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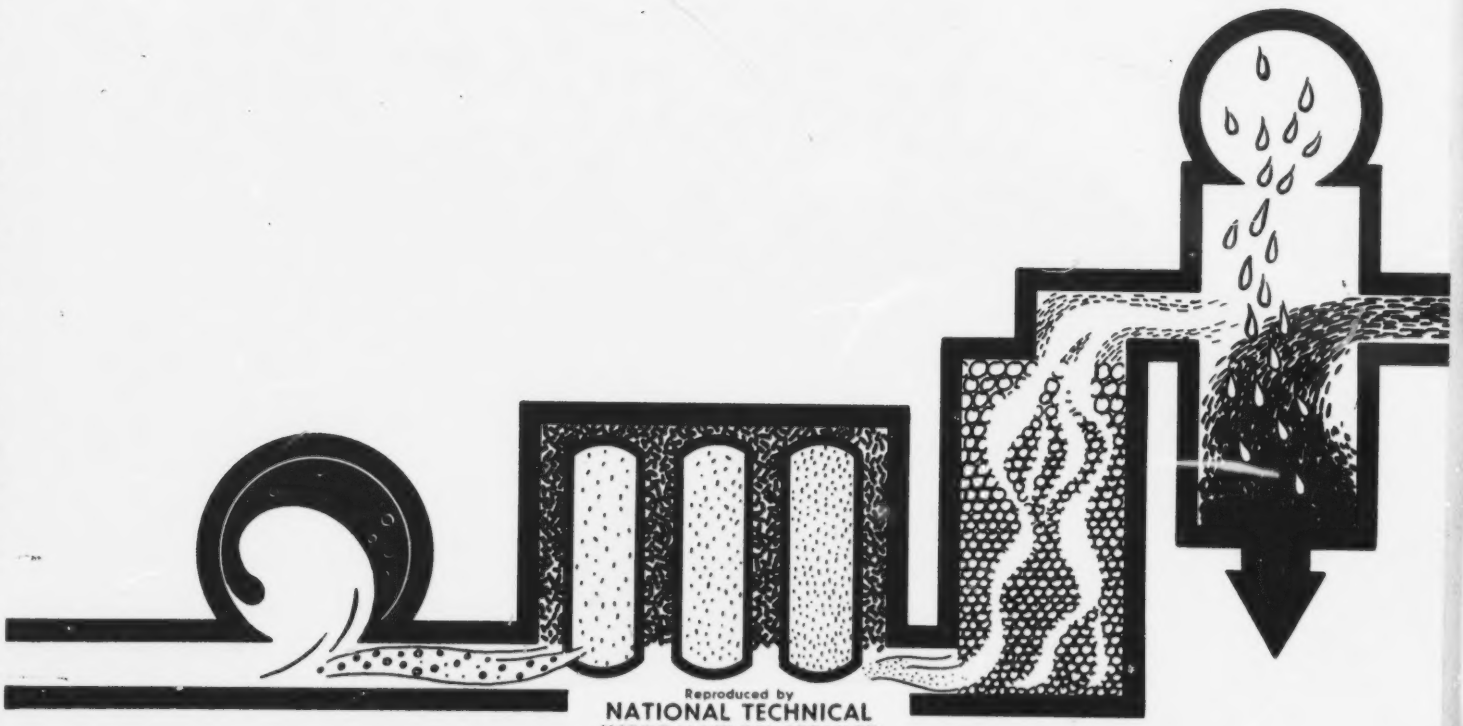
REVERSE OSMOSIS RENOVATION OF PRIMARY SEWAGE



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16. Abstract: A reverse osmosis pilot plant was operated on both primary and secondary effluent for 4 months, and the results were compared. Data indicated that high axial feedwater velocities were necessary to prevent membrane fouling. The main substances causing fouling were suspended particulates, inorganic salt precipitates, and dissolved organic matter, as well as some other substances which are unknown at this time. Suspended particulates were flocculated, settled, and filtered out of the wastes, inorganic salt precipitation was controlled by pH adjustment, except in the presence of calcium sulfate, and dissolved organic matter can be removed by biological treatment. However, by increasing the axial velocity to 12.9 ft./sec. for the primary waste, the same results could be obtained as were obtained using secondary waste at 2.58 ft/sec. Cleansing of the membrane with an enzyme-active laundry pre-soak formulation proved beneficial for both wastes, with sizable flux restorations achieved. Rejections of major pollutants at 2.6 ft/sec were 94% for TDS, 94% for COD, 85% for NH_3-N, and 100% for turbidity. Values at 12.9 ft/sec were 98% for TDS, 98% for COD, and 100% for turbidity. No cost estimates were formulated, and the presence of various inexplicable details indicated the necessity for further experimentations. (Lowry-Texas)

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REVERSE OSMOSIS RENOVATION OF PRIMARY SEWAGE

by

Envirogenics Company
A Division of
Aerojet-General Corporation
El Monte, California 91734

for the

ENVIRONMENTAL PROTECTION AGENCY

Project #17040 EFQ
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ABSTRACT

A 4-month laboratory bench-scale program was conducted at the City of Corona, California, Water Reclamation Plant to investigate the feasibility of renovating primary sewage treatment plant effluent by the reverse osmosis process. Results were obtained on the processing of primary effluent under a variety of operating conditions. Secondary effluent was also processed for comparison.

Maintenance of high feed water axial velocity was the only method of those considered that provided an acceptable product water flux decline with primary effluent. At an axial velocity of 12.9 ft/sec, the performance with primary effluent was comparable to that observed with secondary effluent at 2.58 ft/sec. Axial velocities of 2.58 and 6.45 ft/sec were insufficient to prevent gross membrane fouling with primary effluent.

High indigenous calcium and sulfate concentrations in the sewage resulted in mild calcium sulfate precipitation and unacceptable performance with alum-treated, sand-filtered primary effluent at a 2% product water recovery ratio. At more practical recoveries in excess of 50%, both secondary effluent and alum-treated, sand-filtered primary effluent experienced severe membrane fouling by calcium sulfate deposition.

Sizable restorations in product water flux were achieved by an occasional cleansing with an enzyme-active laundry presoak formulation. Short-term depressurization of the reverse osmosis system for 15 minutes also restored product water flux, but to a lesser extent.

Rejections of major pollutants were high and improved with increasing feed water axial velocity. Values for primary effluent at the lowest axial velocity of 2.58 ft/sec averaged 93.7% for total dissolved solids as measured by electrical conductivity, 94.2% for chemical oxygen demand, 84.7% for ammonium nitrogen, and 100% for turbidity. Corresponding average rejections at an axial velocity of 12.9 ft/sec were 98.0% for total dissolved solids, 97.8% for chemical oxygen demand, and 100% for turbidity.

This report was submitted in fulfillment of Project Number 17040 EFQ, Contract 14-12-885, under the sponsorship of the Water Quality Office, Environmental Protection Agency.

Key Words: *Demineralization, *Reverse osmosis, *Sewage treatment, *Water reuse, Membrane processes, organics removal, solids removal.

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SECTION I

CONCLUSIONS

A number of findings and conclusions are presented, based on the conduct of a 4-month laboratory bench-scale investigation at the City of Corona Water Reclamation Plant to determine the feasibility of treating primary effluent by the reverse osmosis process.

For primary effluent, only the highest of three feed water axial velocities used, namely 12.9 ft/sec corresponding to a nominal Reynolds number of 54,000, provided acceptable product water flux performance at low recovery levels and at a pH of 6.0. After the first day of operation, the product water declined slowly from about 23 to 16 gal./(sq ft)(day) over 14 days. Under the same feed water conditions, axial velocities of 2.58 and 6.45 ft/sec, corresponding to nominal Reynolds numbers of 10,800 and 27,000, respectively, resulted in excessive product water flux declines to less than 3 gal./(sq ft)(day) in just two and seven days, respectively.

Product water flux performance with primary effluent at the 12.9 ft/sec axial velocity was comparable to that obtained with secondary effluent at the lower axial velocity of 2.58 ft/sec.

Pretreatment methods employed in this program were of little benefit in preventing rapid product water flux declines with primary effluent at an axial velocity of 2.58 ft/sec. At low product water recoveries, pH adjustment of the high-calcium and high-sulfate sewage with hydrochloric acid reduced the occurrence of calcium sulfate precipitation and deposition that occurred with sulfuric acid addition, but neither acid substantially reduced the product water flux decline. Addition of the anionic flocculating polyelectrolyte Zimmite 190 was ineffective in preventing membrane fouling. Product water fluxes declined from more than 20 to 2.5 gal./(sq ft)(day) in just four days.

Although removal of suspended and finely dispersed solids by alum addition, flocculation, sedimentation, and sand filtration partially reduced product water flux declines with primary effluent, the reverse osmosis performance remained poor. When using the alum-treated primary effluent at a pH of 5.3 effected with sulfuric acid addition, a feed water axial velocity of 2.58 ft/sec, and at a product water recovery ratio of 2%, the product water flux dropped from 40 to 4 gal./(sq ft)(day) in six days. Maximum performance was obtained when the pH was adjusted to 5.3 with hydrochloric acid; the average product water flux diminished from 30 to 8 gal./(sq ft)(day) in 24 days.

Both secondary effluent and alum-treated, sand-filtered primary effluent produced rapid product water flux declines at an axial velocity of 2.58 ft/sec and at concentrations corresponding to product water

recovery ratios as low as 50%. This was attributed primarily to the precipitation of calcium salts from the wastewaters, which contained high indigenous concentrations of calcium and sulfate.

In the absence of continuous chlorination of the feed water streams, biological growth occurred that severely depressed the product water flux when the feed water pH was that of normal sewage, or 6.8 in this study, and not at the more acidic conditions of pH values of 5.3 or 6.0. Chlorination of feed waters therefore would appear to be a requirement only if feed waters were not acidified to pH levels below about 6.

High removals of major pollutants contained in municipal wastewaters were accomplished by the reverse osmosis process. Rejections were dependent upon feed water quality and operating conditions, with average overall removals ranging from 84 to 98% for total dissolved solids as measured by electrical conductivity, 100% for suspended and dispersed solids as measured by turbidity, from 85 to 98% for oxidizable organics as measured by chemical oxygen demand, and from 88 to 95% for ammonium nitrogen.

Wastewater constituent rejections from primary effluent improved as feed water axial velocities increased, rising from a total dissolved solids rejection of 93.7% at an axial velocity of 2.58 ft/sec to 98.0% at 12.9 ft/sec. This is a consequence of a diminished liquid boundary layer thickness, which creates a smaller salt concentration directly at the membrane surface. Thus operation of the reverse osmosis process at high feed water axial velocities will result in an increased tolerance to dissolved solids concentrations in the feed water stream without attendant decrease in product water quality.

Daily system depressurization for a period of 15 minutes proved beneficial to maintenance of product water fluxes. The degree of flux recovery immediately following depressurization was a function of the rate of product water flux decline. Benefits ranged from 1.1% for primary effluent at an axial velocity of 12.5 ft/sec where the general flux decline was relatively small, to 99.4% for primary effluent at an axial velocity of 2.58 ft/sec where the flux decline was reasonably large.

Unexplained rises and falls in product water fluxes were observed and suggest that certain sewage constituents that were not uniquely characterized by the feed water turbidity and chemical oxygen demand affect membrane performance.

Soaking of a severely fouled membrane in an enzyme-active laundry presoak formulation was often found to be beneficial to the restoration of product water flux.

SECTION II

INTRODUCTION

A major remaining obstacle to municipal wastewater treatment by reverse osmosis systems is the relatively rapid decrease in the capacity of the membrane to transport product water. This decline in production rate is due to two factors: intrinsic compaction or reorientation of the membrane structure, and fouling by dissolved and solid substances contained in the feedwater. In the treatment of municipal wastewaters, the magnitude of the flux decline produced by intrinsic properties of the membrane has proven to be negligible in comparison to that associated with deposits formed on the membrane surface or other interactions between wastewater constituents and the membrane surface.

Whereas the magnitudes of product water flux after a given operating time may be different for various types of municipal wastewaters, reflecting the quality or amount of pretreatment afforded it, the rates of flux decline after several weeks of operation with raw sewage, primary effluent, and secondary effluent were observed to be quite similar (Ref. 1). These similar decline rates would appear to indicate that the fouling mechanism likewise is the same for these wastewaters, and the means of inhibiting or eliminating flux decline for one wastewater should apply equally to the others. Therefore, renovation of primary sewage by reverse osmosis was indicated to reduce the degree of pretreatment to a minimum. Raw sewage was excluded from consideration due to its abrasive character.

To substantiate earlier findings under more realistic conditions, a 4-month laboratory-scale, field-test program was conducted. Tests were performed at the sewage treatment facility of the City of Corona, California, to provide a continuous supply of fresh primary and secondary sewage to the reverse osmosis units, which provided a small membrane surface area of less than 2.4 sq ft and which were operated in either a nonrecirculating or recirculating mode.

SECTION III

PROCEDURES

This program was conducted at the City of Corona Water Reclamation plant, which employs the activated sludge process presently operating at one-half its design flow of 5.5 mgd. The facility consists of preliminary screening, primary sedimentation, mixed liquor aeration, secondary sedimentation, and anaerobic sludge digestion, with supernatant return to the primary sedimentation tank.

TEST APPARATUS

The reverse osmosis membranes used in this program were cast from a cellulose acetate-cellulose triacetate blend with a degree of acetyl substitution of 2.63. Initial osmotic properties of individual membranes observed with a one percent pure sodium chloride solution at 700 psig ranged from 22.3 to 45.0 gal./(sq ft)(day) for product water flux and from 80.5 to 95.4% for salt rejection. These fluxes are equivalent to membrane coefficients of from 22.1 to 44.5 μg/(sq cm)(sec)(atm), respectively. The average initial water flux was 33.6 gal./(sq ft)(day) and the average initial sodium chloride rejection was 87.1%. Detailed data on initial osmotic properties of the membranes are presented in Appendix A.

The membranes were cast into polyester sleeves that were subsequently inserted into tubular braided fiberglass-resin shells with a 0.56-in. finished internal diameter. The membraned tubes were fitted with bonded-on, or in later versions molded-on, end fittings and inserted into polycarbonate return bends supported by a steel frame.

Four separate reverse osmosis test apparatus were used. Three consisted of four 52-in. long reverse osmosis tubes placed in series flow configuration that were operated without recycling of the wastewater reject stream through the unit. These units provided a total effective membrane area of 2.4 sq ft. The fourth test apparatus contained two 52-in. long reverse osmosis tubes (1.2 sq ft total) in series flow configuration that was operated with recirculation of the reject stream. Schematic flow sheets of the test apparatus are shown in Figure 1.

High-pressure pump capacities for the four units differed. Two of the nonrecirculating systems were equipped with progressing cavity pumps of 7-gpm rated capacity each, whereas the third was supplied from two diaphragm pumps of 1-gpm rated capacity placed in parallel flow configuration to deliver a total of 2 gpm. The recirculating reverse osmosis unit was likewise equipped with two parallel-mounted diaphragm pumps of 1-gpm rated capacity that supplied a total of 2 gpm.

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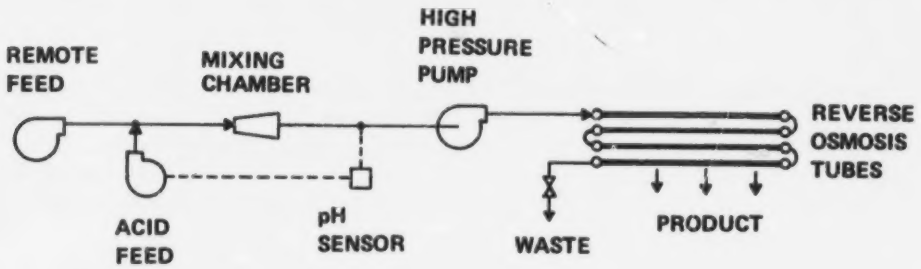
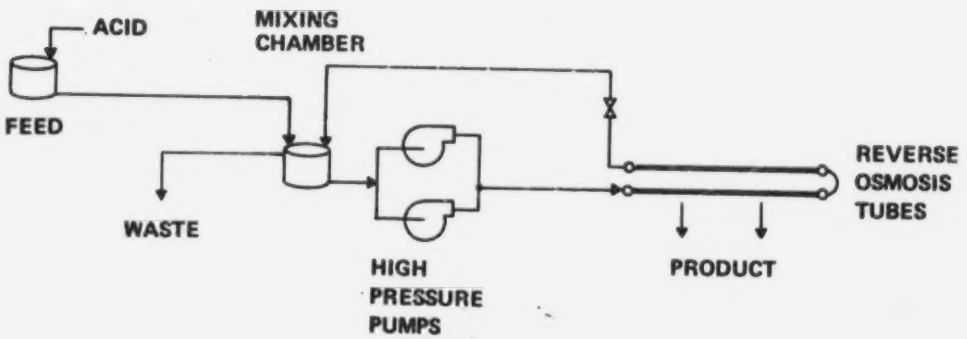


Nonrecirculating System



Recirculating System

Figure 1. SCHEMATIC FLOW SHEETS OF REVERSE OSMOSIS TEST APPARATUS

At the start of the program on 22 July 1970, all tubes were placed in a vertical attitude to facilitate installation and product water collection from individual tubes. Tube failures were experienced that could be attributed to the occurrence of negative pressures inside the membrane sleeve at the top end of the tube during regular depressurization operations. On 9 September 1970 all tubes were changed to a horizontal attitude to eliminate this condition. Both the vertical and horizontal arrangements of a 4-tube nonrecirculating reverse osmosis test apparatus are shown in Figure 2.

FEED WATERS

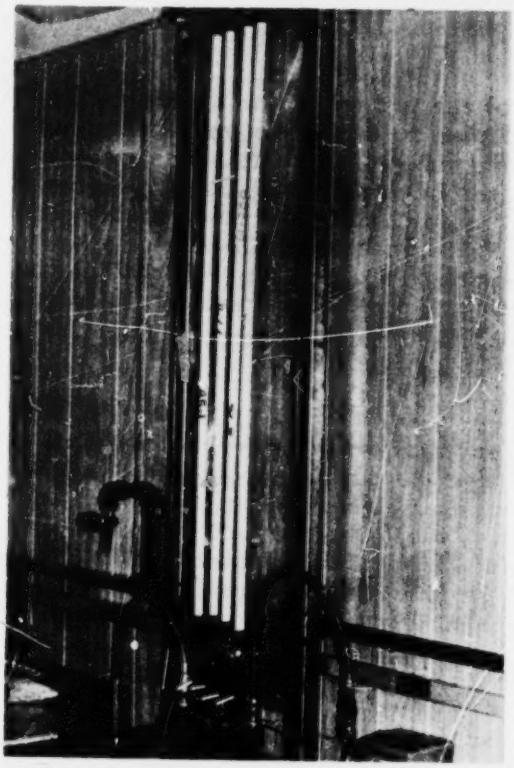
Sewage was supplied to the reverse osmosis test facilities continuously by means of remote pumps located in the overflow channels of the primary and secondary sedimentation tanks, and thus represented the normal diurnal variations in quality encountered at sewage treatment plants. In addition, alum-treated, sand-filtered primary sewage was continuously produced by a complete packaged clarification plant rated at 3.8 gpm. The plant, pictures in Figure 3 in front of the laboratory trailer, consisted of a chemical solution tank and feeder, rapid mixer, sedimentation basin, pressure sand filter, and clearwell.

Wastewater analyses provided by the City of Corona Water Reclamation Plant on 24-hour composite samples collected during the test program period are presented in Table 1. Influent raw sewage quality appeared to remain generally unchanged over the study period, with the exceptions of several isolated high concentrations of chemical oxygen demand and suspended solids and a slightly increasing trend of biochemical oxygen demand concentration. The sewage is high in total hardness and total dissolved solids, which can be attributed to the water supply in the area.

Average BOD removal by the primary treatment portion of the plant during the program was 48.2% if the results reported for the period 14 through 29 September 1970 are discarded. For the comparable period the average suspended solids removal was 66.3% in the primary process.

During the last half of September the Water Reclamation Plant was experiencing one of the three episodes of operational difficulties encountered during the program. The other two episodes occurred at the end of August and middle of October between the reported dates for wastewater characteristics, so that they are not in evidence in Table 1. These upsets were characterized by excessive foaming in the aeration tanks and rising sludge in the secondary sedimentation basins. During the September occurrence, the average BOD and suspended solids removals by the primary process were reduced to 26.4 and 59.2%, respectively.

From the data reported in Table 1, the overall BOD removal efficiency of the Water Reclamation Plant during the period of this program was 90.1 percent.



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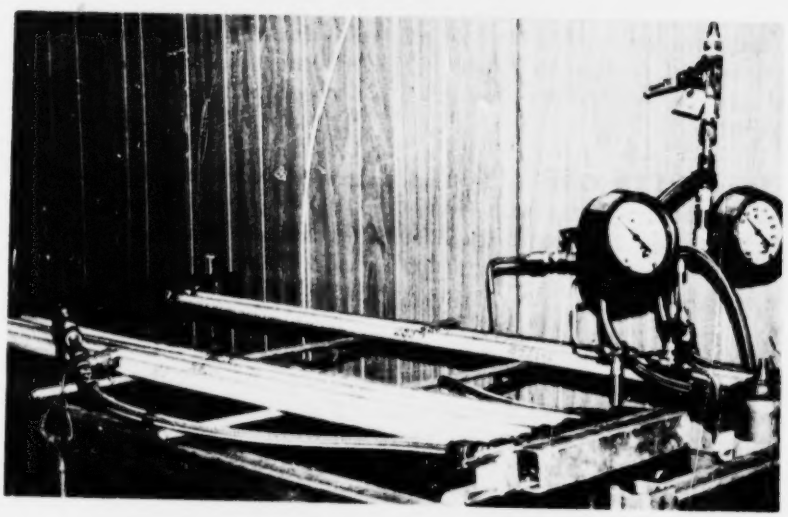
Vertical Attitude



Horizontal Attitude

Figure 2. REVERSE OSMOSIS TEST APPARATUS

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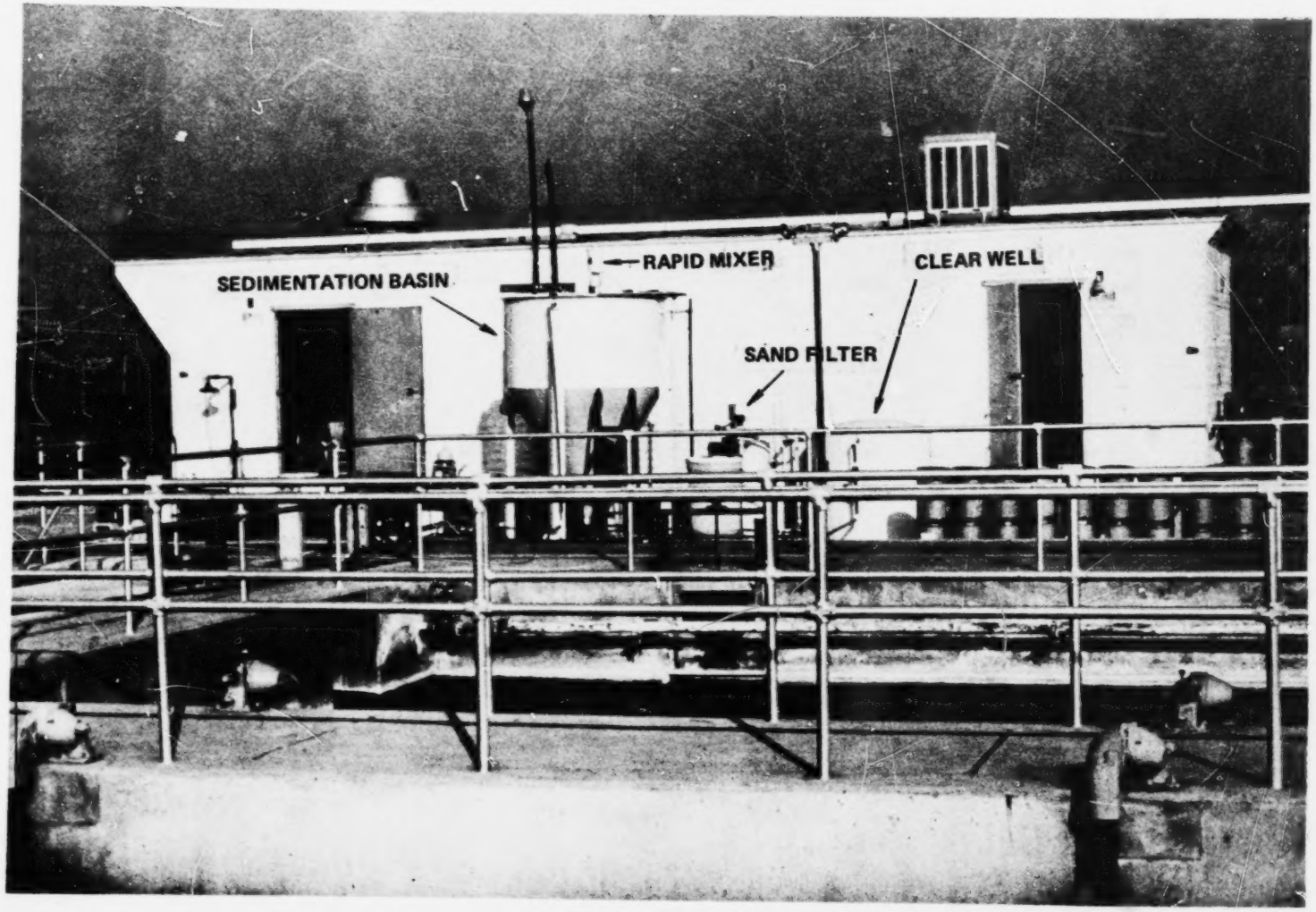

Figure 3. LABORATORY TRAILER AND PRIMARY EFFLUENT CLARIFICATION UNIT

Table 1

WASTEWATER CHARACTERISTICS, CITY OF CORONA WATER RECLAMATION PLANT

(mg/l)

	Date																
	7-21	7-23	7-30	8-4	8-5	8-11	8-18	8-25	9-9	9-14	9-17	9-24	9-29	10-6	10-8	10-20	10-25
Plant Influent (Raw Sewage)																	
Suspended Solids	228	253	250	-	222	231	240	207	337	275	200	237	213	426	244	275	253
BOD	198	173	234	-	255	240	236	-	275	220	198	192	270	318	288	268	274
Total COD	512	492	524	404	-	445	-	-	-	-	-	-	404	756	-	449	447
Primary Sewage																	
Suspended Solids	85	97	73	-	87	90	98	80	99	101	80	98	96	91	80	71	83
BOD	105	90	120	113	128	115	-	146	144	153	147	138	213	159	173	135	-
Plant Effluent (Secondary Sewage)																	
Suspended Solids	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BOD	32	25	32	11	-	20	-	-	-	-	-	-	7	-	-	19	20
Total COD	32	48	63	48	-	44	-	-	-	-	-	-	37	50	-	47	43
Electrical Conductivity*	1700	1650	1650	1700	-	1675	-	-	-	1650	1600	-	1650	1650	-	1675	-
Total Dissolved Solids	1025	1019	991	1033	-	1033	-	-	-	-	999	-	1013	970	-	-	-
Chloride	265	250	255	250	-	250	-	-	-	245	250	-	240	235	-	335	-
Sulfate	170	195	170	195	-	180	-	-	-	165	155	-	175	153	-	235	-
Hardness, as $CaCO_3$	342	308	325	325	-	308	-	-	-	325	342	-	325	308	-	342	-

*μmhos/cm at 25°C

OPERATING CONDITIONS

All tests were conducted on a continuous basis, 24 hours a day, 7 days a week with a routine daily depressurization of about 15 minutes. This daily shutdown was provided to assist in the maintenance of product water flux through the membrane and to allow scheduled cleaning of system components such as electrodes in the pH controllers.

Tests were run at 700-psig operating pressure with all depressurization going to zero psig in no less time than 20 seconds. Feed water flow rate was 2 gpm (10,800 calculated nominal Reynolds number, 2.58 ft/sec/axial velocity) except for two instances with primary sewage feed where the flow rate was 5 gpm (27,000 Reynolds number, 6.45 ft/sec axial velocity) and 10 gpm (54,000 Reynolds number, 12.9 ft/sec axial velocity).

Product water recovery ratios except for the first few hours of operation when very high product water fluxes occurred with virgin membranes, were less than 2% for the nonrecirculating systems. The recirculating system was operated at several product water recovery ratios ranging from 50 to 90%. Upon attaining the desired recovery ratio, as determined volumetrically from the feed and product waters, the electrical conductivity was recorded and thereafter maintained at that level throughout the test. The recirculating system was fed by gravity from a storage container replenished on a daily basis. Initial concentrations of all feed waters were effected with the same membrane utilized for the conduct of the test at the elevated recovery ratio.

Chemical addition prior to reverse osmosis processing was accomplished in the low-pressure sewage feed line. For pH adjustment, controllers intermittently injected predetermined amounts of acid into the feed line to produce the necessary pH change. The sewage proceeded to an expansion-mixing chamber and then to the pH sensing electrodes. An excess amount of acid was countered by an automatic acid feed shutoff that was restarted when pH rose above a preset level. A pH of 5.3 was the lowest stable value that could be maintained with the equipment used.

The addition of other chemicals to prevent deposition of wastewater substances on the membrane was accomplished upstream of the expansion-mixing chamber. Zimmite 190, an anionic polyelectrolytic flocculating agent, was used on the basis of its successful application in a previous laboratory program (Ref. 1). The addition of chlorine, while not standard practice, was necessitated at times to prevent biological growth on the membrane surfaces. An enzyme-active laundry presoak formulation used as a membrane cleanser was injected under low pressure into the depressurized system immediately upstream of the reverse osmosis tubes and allowed to soak for 10 minutes. The manufacturer's recommended dosage for stain removal of 2 tbsp/gal. of water was used at ambient temperature and pressure. A 2- to 5-gpm

tap water flush for several minutes followed the soaking, removing all loose particulate matter and the bulk of the presoak formulation from the reverse osmosis tubes.

Chemical-physical removal of suspended matter from primary effluent was accomplished in an alum clarification plant, especially built to handle the low flows encountered in this project. Primary effluent was fed at 3.8 gpm into a rapid-mix pipe where 300 mg/l of commercial grade aluminum sulfate was added to the main stream. Optimum dosage was established and frequently checked by the standard jar test procedures. From the rapid mix pipe, the flow proceeded to a slow-mix chamber with a retention time of 28 minutes. Ports in the bottom of the chamber, which was suspended in an 800-gal. circular sedimentation basin, discharged flocculated solids and the main liquid stream to a 3.5-hour gravity separator with a surface loading rate of 400 gal./(sq ft)(day). Clarified effluent from this tank proceeded to a pressurized sand filter and thence to a 375-gal. clear well, which supplied the 2-gpm flow required by the reverse osmosis test apparatus and sufficient storage to backwash the filter every six hours.

MEASUREMENTS

Product water flux was determined for individual tubes by collecting a fixed volume over a known time period. Reported values were determined at 1300 hours daily. Electrical conductivity, pH, turbidity, chemical oxygen demand, and ammonium concentrations of feed and product streams were monitored and analyzed in accordance with procedures outlined in the Twelfth Edition of Standard Methods for the Examination of Water and Wastewaters (Ref. 2).

Electrical conductivity was measured on batch samples with a conductivity bridge and a 1-ml immersion probe.

A continuous record of the pH in the nonrecirculating systems was obtained. The pH in the recirculating system was measured five times daily over an 8-hour period, with a meter using a glass electrode and calomel reference cell.

Turbidity of the feed water streams was measured daily by an electronic turbidimeter, Hach Model 1860A. Product water streams were intermittently measured but were found to be below the range of accurate sensitivity of the instrument; i.e., less than 0.2 Jackson turbidity units (Jtu).

Total chemical oxygen demand concentrations were determined thrice weekly by potassium dichromate-sulfuric acid digestion for two hours and ferrous ammonium sulfate titration to the ferrous indicator endpoint. Chloride present in the sample was complexed with mercuric sulfate.

Ammonium, in weekly samples, was distilled from Kjeldahl flasks, collected in boric acid solution, and quantified colorimetrically at 476-mμ wavelength in a spectrophotometer following Nesslerization.

In addition to these routine analyses, solids samples from membrane surfaces and liquid stream samples were analyzed occasionally for calcium, total phosphorus, sulfate, carbonate, and total volatile matter by an independent laboratory in accordance with Twelfth Edition of Standard Methods (Ref. 2).

Grab samples for chemical oxygen demand and ammonium analyses were collected at 1100 hours. Other liquid analyses were performed on grab samples taken at 1300 hours for the product water flux determination.

SECTION IV

LABORATORY RESULTS

Performance of the reverse osmosis process is characterized by the product water flux and wastewater constituent rejections, which are dependent upon a combination of factors including membrane type, feed water quality, operating pressure, product water recovery ratio, feed water velocity, and type and dosage of additives. The results described herein reflect these influences, which are presented as they were investigated within particular feed water groupings.

Average feed water qualities directly affecting membrane performance are presented in Table 2. Samples for analysis were taken just prior to the liquid stream entering the reverse osmosis tubes; therefore, while the nonrecirculating systems may have been operating at a 2% product water recovery ratio condition, the feed waters were at a zero recovery condition and are so labeled. Inspection of Table 2 will reveal that for alum-treated, sand-filtered primary sewage and secondary sewage, feed water constituent concentrations decrease, instead of increase, or are not as high as would be expected at the higher recovery ratios of 80 and 90%. This is attributed in part to the method of volumetrically establishing product water recovery ratio conditions, wherein a single batch sample is concentrated and future electrical conductivity values established at that time. The single sample of feed water used in the initial concentration may have differed sufficiently in composition from that of subsequent samples to produce this effect. Also decreasing turbidities and total organics with increasing recovery ratio may be caused by agglomeration of particulates and oxidation of organics in the strongly agitated, recirculating system used for high recovery ratio test conditions. Electrical conductivity is not so easily influenced by these conditions on the other hand, due to the fact that its level is artifically maintained at a constant value.

Some initial product water fluxes will be depicted in subsequent illustrations well in excess of those recorded in Appendix A for initial membrane properties. This is due in part to the fact that all new membranes during the first few minutes of pressurization exhibit high transient fluxes which are not measured during the production line quality-control test. When the high transient fluxes occurred near a scheduled sampling period, they were recorded for that period. Furthermore, the standard saline solution of 10,000 mg/l sodium chloride used in the quality-control tests exerts a greater osmotic pressure than does sewage with approximately 1,200 mg/l of total dissolved salts, which results in a naturally higher product water flux with sewage feed at any given operating pressure.

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Table 2

AVERAGE FEED WATER CONSTITUENT CONCENTRATIONS

Feed Water	Recovery, %	Temperature, °C	EC[a]	Turbidity, Jtu	Constituent: Total COD, mg/l	NH_4-N, mg/l	Total P, mg/l	Ca, mg/l	SO_4, mg/l
Primary Effluent	0	32	1969	61	230	4.0	18.3[b]	98[b]	181[b]
Alum-treated, Sand-filtered Primary Effluent	0	34	2182	3.8	80	3.6	0.06[b]	108[b]	360[b]
	65	35	4875	4.2	202	7.3	-	-	-
	90	36	9400	4.8	127	-	-	-	-
Secondary Effluent	0	31	1872	5.6	67	2.7	-	-	-
	50	32	3381	10.6	211	10.5	-	-	-
	70	33	4133	10.9	197	-	-	-	-
	80	33	3856	8.8	147	-	-	-	-

[a]Electrical Conductivity, μmhos/cm at 25°C

[b]Single sample preceding acidification

PRIMARY EFFLUENT

Primary effluent feed water was relatively unchanged, except for pH adjustment and addition of a solids deposition inhibitor, and was tested in the nonrecirculating apparatus. The test was started with sulfuric acid for adjustment of the pH to 6.0 – a level shown by previous experience to be optimum for maximum effectiveness of the Zimmite 190 additive. Figure 4 shows the ineffectiveness of both the Zimmite 190 and the pH adjustment in preventing severe flux decline during the first 50 days of operation at axial velocities of 2.58 or 6.45 ft/sec. Frequent enzymatic cleansings were necessary because of the very rapid drops in product water flux. No improvement in results was noted despite the use of various dosages of the Zimmite additive. An analysis of membrane deposits taken from this system operated at a pH of 6.0 maintained with sulfuric acid and at 2 mg/l Zimmite 190 revealed 3.55% phosphorus, 2.46% calcium, 5.44% sulfate, 73.78% volatile matter, and 14.77% unidentified material. The relatively high abundance of calcium, sulfate, and phosphorus indicated that salt precipitates may be significant factors in membrane fouling.

Subsequent tests conducted with hydrochloric acid at a pH of 5.3 in order to reduce calcium sulfate and phosphate deposition did not result in improved product water flux. Analysis of membrane deposits from a test with hydrochloric acid and Zimmite 190 indicated 3.23% phosphorus, 0.94% calcium, 0.11% sulfate, 73.67% volatile matter, and 23% unidentified material. Discontinuation of sulfuric acid addition apparently prevented major calcium sulfate deposition but did not prevent product water flux decline.

Because the various pretreatments were unsuccessful in preventing membrane fouling, a set of tests was initiated to measure the effects of varying the feed water axial velocity from the standard of 2.58 ft/sec (10,800 Reynolds number, 2-gpm feed rate). The first test with a feed water axial velocity of 6.45 ft/sec (27,000 Reynolds number, 5-gpm feed rate) did not produce an acceptable product water flux but did result in a substantially reduced flux decline as shown in Figure 5.

A subsequent test with feed water axial velocity of 12.9 ft/sec (54,000 Reynolds number, 10-gpm feed rate) resulted in a dramatic improvement in membrane performance. The test was marred by tubular structure failures and terminated prematurely by pumping equipment failures but nonetheless presented adequate data showing working solutions to the membrane fouling problem indicated by Figures 4 and 5. In the one tube lasting the entire test period, the flux declined from 27 to 14 gal./(sq ft)(day) over a period of 15 days and was not very unlike declines obtained with secondary sewage.

Periodic depressurization of the reverse osmosis system did result in improved product water flux when measured immediately upon restarting operation. Immediate flux recoveries for axial velocities of 2.58, 6.45 and 12.9 ft/sec were 99.4, 3.4, and 1.1%, respectively.

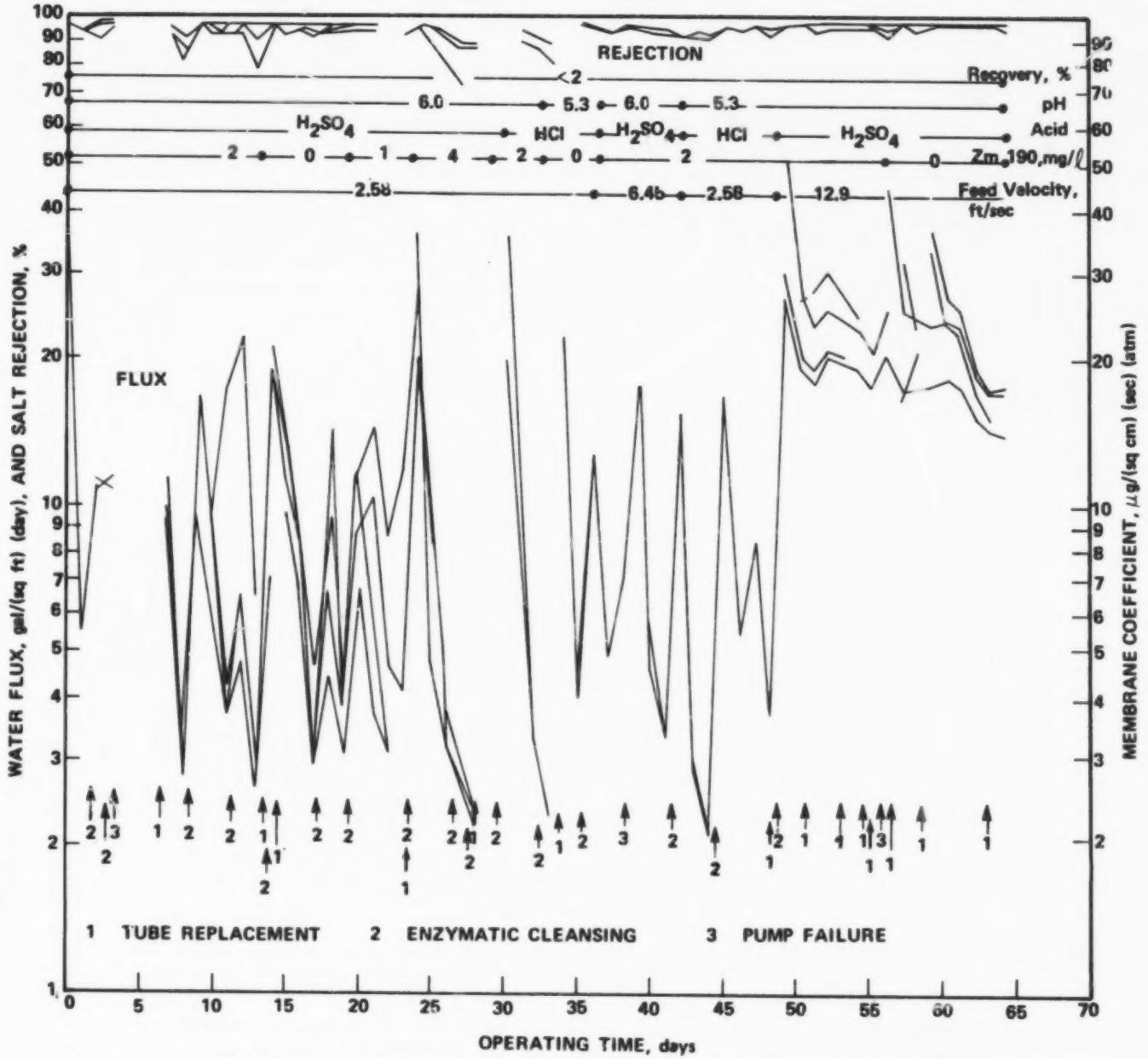

Figure 4. REVERSE OSMOSIS PERFORMANCE WITH ZIMMITE 190-TREATED PRIMARY EFFLUENT, NONRECIRCULATING SYSTEM AT 700 psig

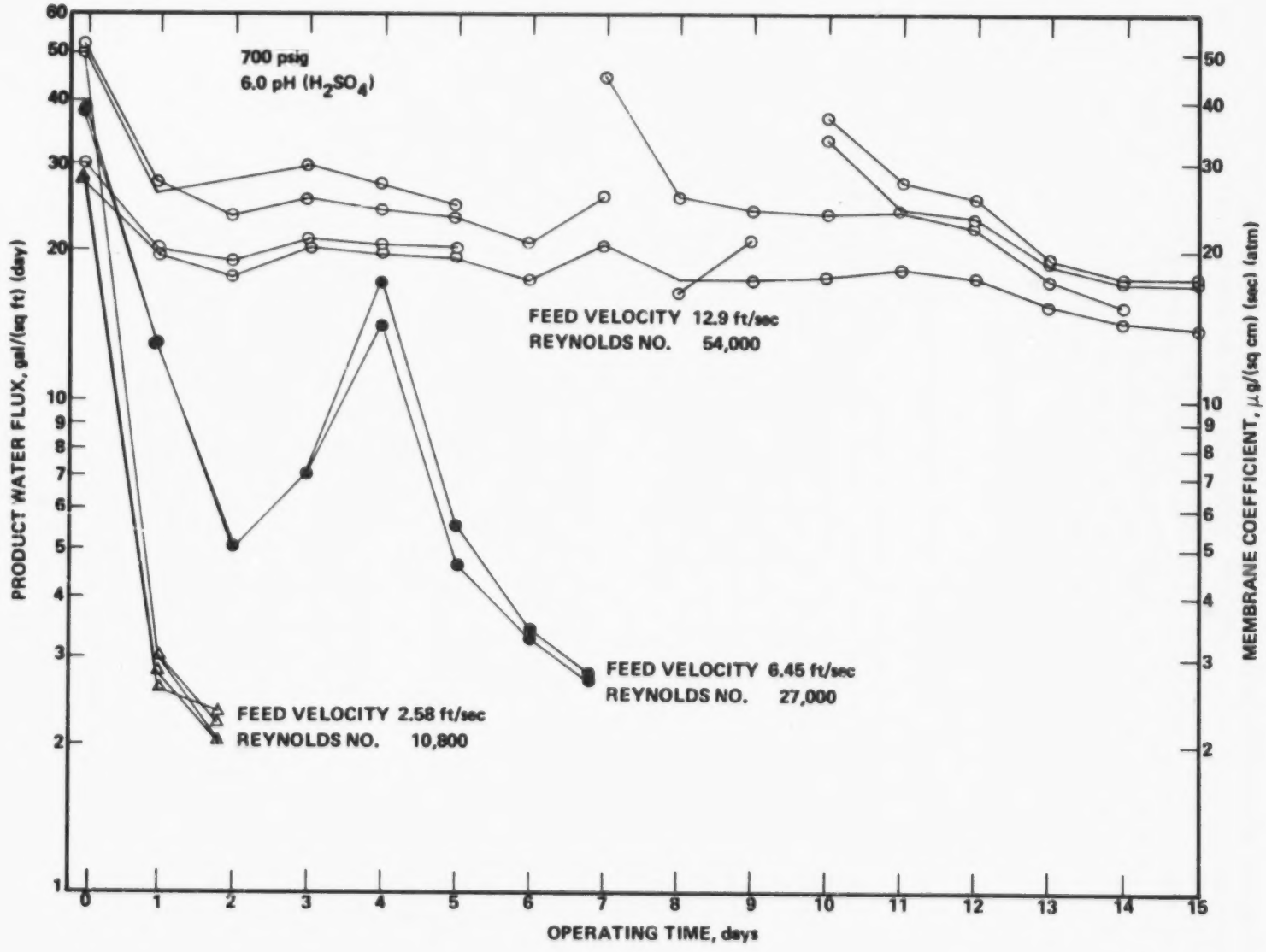
700 psig
6.0 pH (H_2SO_4)
FEED VELOCITY 12.9 ft/sec
REYNOLDS NO. 54,000
FEED VELOCITY 6.45 ft/sec
REYNOLDS NO. 27,000
FEED VELOCITY 2.58 ft/sec
REYNOLDS NO. 10,800
PRODUCT WATER FLUX, gal/(sq ft) (day)
MEMBRANE COEFFICIENT, μg/(sq cm) (sec) (atm)
OPERATING TIME, days

Table 3, which presents wastewater constituent rejections for the various principal test conditions, indicates that the constituent rejections for dissolved solids (EC), chemical oxygen demand (COD), and ammonium (NH_4^+) substantially improved with increasing feed water axial velocity. The change in the dissolved solids rejection alone was from 93.7% at 2.58 ft/sec to 98.0% at 12.9 ft/sec. No evidence of unusual membrane deterioration was observed during this test period. Tube replacements were necessitated almost solely by structural support failures.

Daily product water flux and pollutant rejection data are tabulated in Appendix B.

ALUM-TREATED, SAND-FILTERED PRIMARY EFFLUENT

Alum-treated, sand-filtered primary effluent is characterized by having a lower suspended and dispersed solids content than primary effluent and a higher dissolved organic chemical content than secondary effluent. It was anticipated that this type of feed water would eliminate membrane fouling by finely dispersed solids and provide long-term, low flux decline performance. Figure 6 demonstrates, however, that for the longest duration run of 24 days the product water flux declined from 20 (ignoring the much higher transient flux) to 8 gal./(sq ft)(day) with alum-treated, sand-filtered primary effluent in the nonrecirculating apparatus. The reasons for this performance were many and varied.

The initial test with alum-treated, sand-filtered primary effluent was conducted at an average pH of 5.3, adjusted with sulfuric acid. The product water flux decline was rapid, and visual observation of membrane surfaces indicated inorganic salt precipitation. An analysis was run on the alum clarification plant output and revealed 108 mg/l calcium and 360 mg/l sulfate. These data together with the calculated acid addition revealed the following calcium and sulfate contributions in the feed water:

Calcium:	Indigenous	2.7 mmol/l
Sulfate:	Indigenous	3.8 mmol/l
	Alum	1.4 mmol/l
	Acid	4.9 mmol/l

At this indicated solution ionic strength and at a 2% product water recovery ratio condition, these values result in calcium sulfate saturation with a concentration polarization of only 3.4 at the membrane surface. Thus calcium sulfate precipitation cannot be ruled out as a possible cause of product water flux depression under these operating conditions.

Table 3

AVERAGE WASTEWATER CONSTITUENT REJECTIONS AND PRODUCT WATER QUALITY

Feedwater	Axial Velocity, ft/sec	Recovery, %	Rejections, % EC*	Turbidity	Total COD	NH_4-N	Product Water Quality EC*	Turbidity, Jtu	Total COD, mg/l	NH_4-N, mg/l
Primary Effluent	2.58	2	93.7	100	94.2	84.7	125	<0.1	12.9	0.61
	6.45	2	95.5	100	96.0	89.5	85	<0.1	9.9	0.40
	12.9	2	98.0	100	97.8	-	39	<0.1	5.5	-
Alum-treated, Sand-filtered Primary Effluent	2.58	2	94.0	100	85.4	88.1	130	<0.1	11.7	0.43
	2.58	65	93.7	100	95.0	90.8	307	<0.1	10.2	0.67
	2.58	90	95.7	100	-	-	404	<0.1	-	-
Secondary Effluent	2.58	2	96.9	100	94.6	90.4	58	<0.1	3.7	0.26
	2.58	50	84.2	100	96.4	95.3	536	<0.1	7.7	0.50
	2.58	70	86.8	100	96.5	-	547	<0.1	6.8	-
	2.58	80	85.3	100	97.0	-	567	<0.1	4.5	-

*Electrical Conductivity, μmhos/cm at 25°C

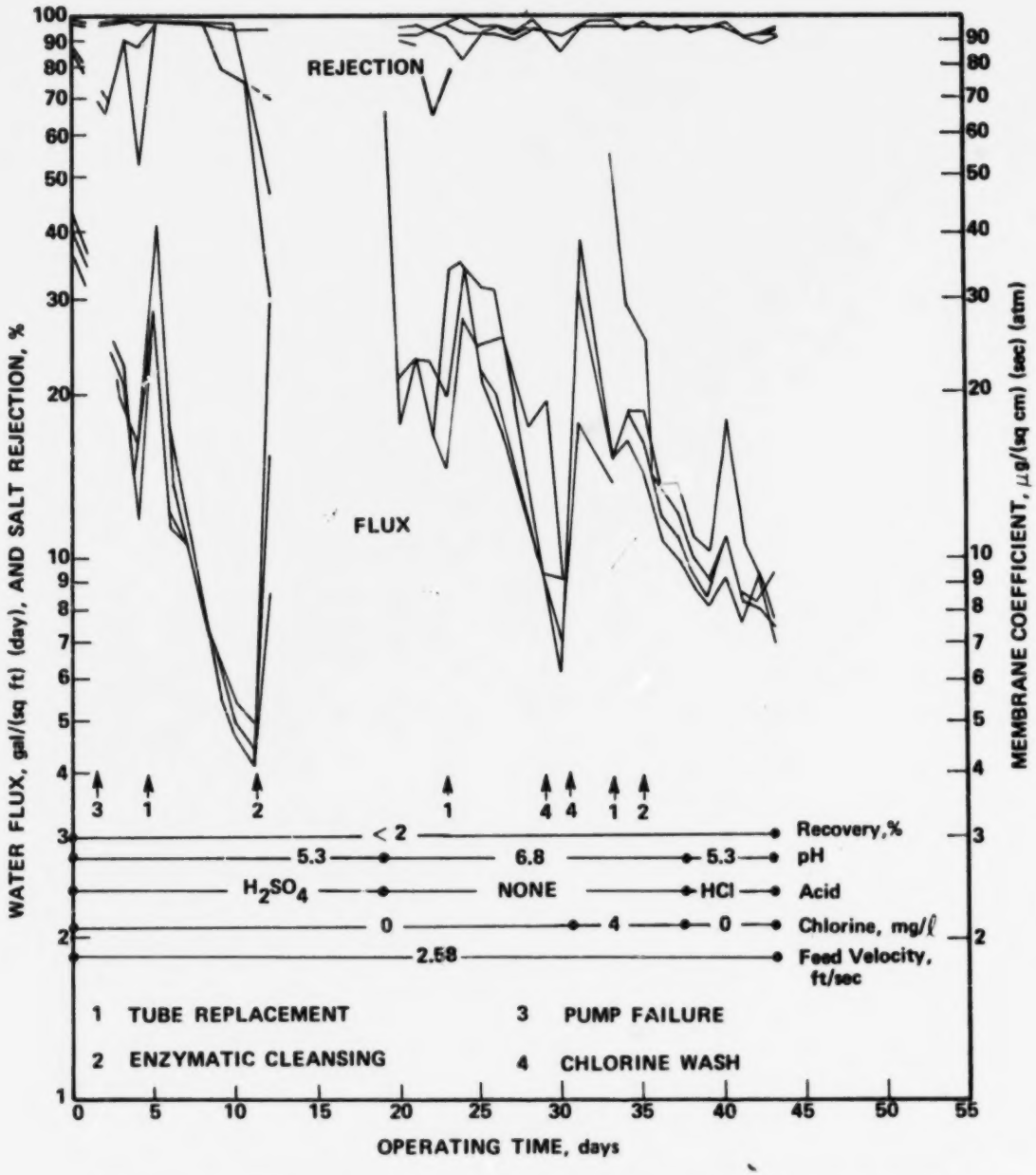

Figure 6. REVERSE OSMOSIS PERFORMANCE WITH ALUM-TREATED SAND-FILTERED PRIMARY EFFLUENT, NONRECIRCULATING SYSTEM AT 700 psig

Reasoning that no addition of sulfuric acid would result in less chance of calcium sulfate precipitation, the next test was conducted with no pH adjustment. Operation of the system at a natural pH of 6.8 did result in a slight reduction in flux decline, but anticipated results were not achieved. Visual inspection of the membrane surfaces revealed a thick fluffy green organic growth that was easily removed and beneath which the membranes were very clean. The membranes were then twice washed for 20 minutes with 30 mg/l of chlorine. The washings resulted in removal of large quantities of brown organic matter followed by a dramatic improvement in product water flux. Chlorination was instituted on a continuous basis at 4 mg/l dosage. Chemical analyses of the fluffy growth disclosed 1.71% phosphorus, 0.25% calcium, 0.74% sulfate, 1.19% carbonate, 67.13% volatile matter, and 28.98% unidentified material. These proportions indicate that cellular material could be the principal constituent of the membrane deposits.

Insoluble phosphate deposition, a potential occurrence at pH values above 5, was not seriously considered because of the high phosphate removal efficiency of the alum clarification process. Analyses, presented in Table 2, indicated only 0.06 mg/l of phosphorus in the alum clarification plant clearwell.

The removal of organic growth from the membrane surface was immediately followed by a resumption of the substantial product water flux decline. To prevent the possible occurrence of calcium carbonate deposition at the relatively high pH level, hydrochloric acid was added to the feed stream to obtain a pH of 5.3. Visual inspection of the membranes indicated that the new material coating the membrane was unlike the previous "growth" and chlorination was discontinued. Product water flux continued to drop at the steady rate shown in Figure 6 during the period between the 37th and 43rd operating days. The test was shortly thereafter discontinued with a final analysis of membrane deposits providing 0.044% calcium, 4.98% sulfate, 0.38% carbonate, 4.2% phosphorus, 71.62% volatile matter, and 18.78% unidentified material.

Daily system depressurization for 15 minutes accounted for an average immediate product water flux increase of 18.1%.

Wastewater constituent rejections for the alum-treated, sand-filtered primary effluent are presented in Table 3. The relatively low COD rejection of 85.4% was in part due to the relatively high ratio of dissolved to suspended organic matter present in this sewage. Dissolved organic matter, more easily transported through the membrane than suspended matter, lowers the COD percentage rejection below that obtained with other sewages. Specific details on membrane performance with alum-treated, sand-filtered primary effluent are available in Appendix C.

The comparison test with concentrated, i.e., high product water recovery ratio, alum-treated, sand-filtered primary effluent was originally started at 90% product water recovery ratio and a pH of 5.3

adjusted with sulfuric acid. Product water fluxes regularly declined to zero within one day, as shown in Figure 7, necessitating frequent restorations of membrane flux with an enzyme-active laundry presoak formulation. Analysis of the membrane deposits indicated that 77% by weight was calcium sulfate; the remaining 23% was unidentified.

Chemical analyses and equilibrium calculations indicated that an estimated maximum product water recovery ratio of 70% may be allowed with no sulfuric acid addition before calcium sulfate precipitation is expected to occur. The test was restarted at a natural pH of 7.2 with no acid addition and a recovery ratio of 65%. The improvement in product water flux decline was dramatic but short of acceptable performance. A pump failure necessitated operation at one-half feed rate capacity (1.29 ft/sec axial velocity) over a portion of the test, but it did not appear to have had a decided influence on membrane performance. An attempt to rescue the test from possible salt deposition problems by reducing the feed water pH to 5.0 with hydrochloric acid did not alter the flux decline. The test was therefore discontinued.

Average flux increase due to daily 15-minute system depressurization for the combined 90 and 65% product water recovery ratio conditions was 16.7%.

Due to the shortness of the text periods for the alum-treated, sand-filtered primary effluent processed in the recirculating system, the specific wastewater constituent rejections, presented in Table 3, for COD and ammonium nitrogen are the result of a small number of samples and should be compared with caution. Daily product water fluxes and wastewater constituent rejections are given in Appendix D.

SECONDARY EFFLUENT

Tests at a product water recovery ratio of less than 2% over most of the test period were conducted at a pH of 5.3 using sulfuric acid for adjustment, at a nonrecirculating feed water axial velocity of 2.58 ft/sec, at a 700-psig operating pressure, and with a daily 15-minute depressurization.

Product water flux, with secondary effluent, shown in Figure 8, exhibited a moderate decline from a high transient of 35 gal./(sq ft)(day) to a low of 6.7 gal./(sq ft)(day) over an initial period of 65 days. Following a 10-minute soak of the membranes with an enzyme-active laundry presoak formulation, the fluxes of the older tubes were restored to 50% of their original values. Thereafter a product water flux decline similar to that noted earlier repeated itself for the duration of the 98-day test.

It is interesting to note the similar behavior of the four tubes in the system with regard to flux increases and decreases, demonstrating most likely the dependence of performance on varying feed water quality.

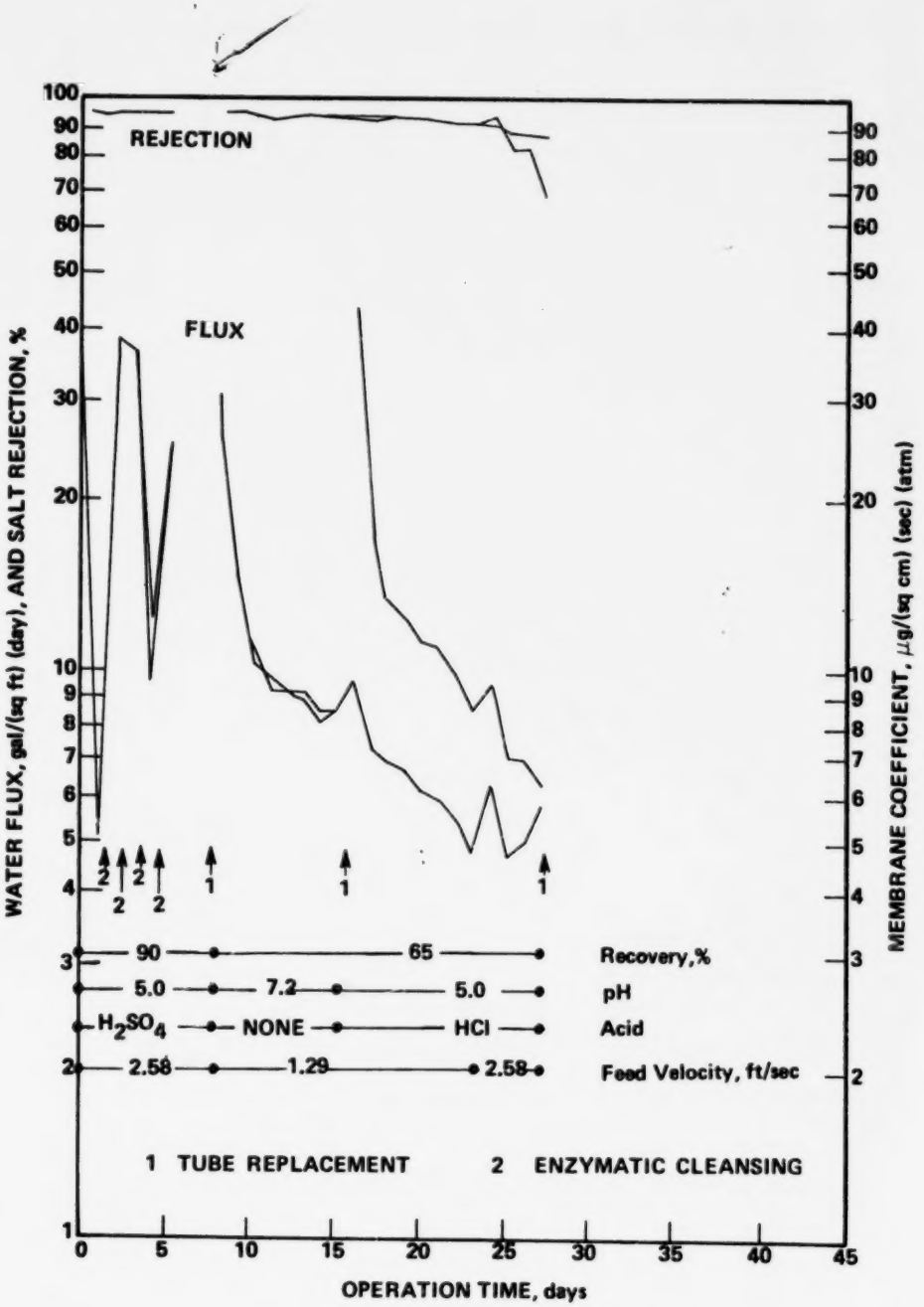

Figure 7. REVERSE OSMOSIS PERFORMANCE WITH CONCENTRATED ALUM-TREATED, SAND-FILTERED PRIMARY EFFLUENT, RECIRCULATING SYSTEM AT 700 psig

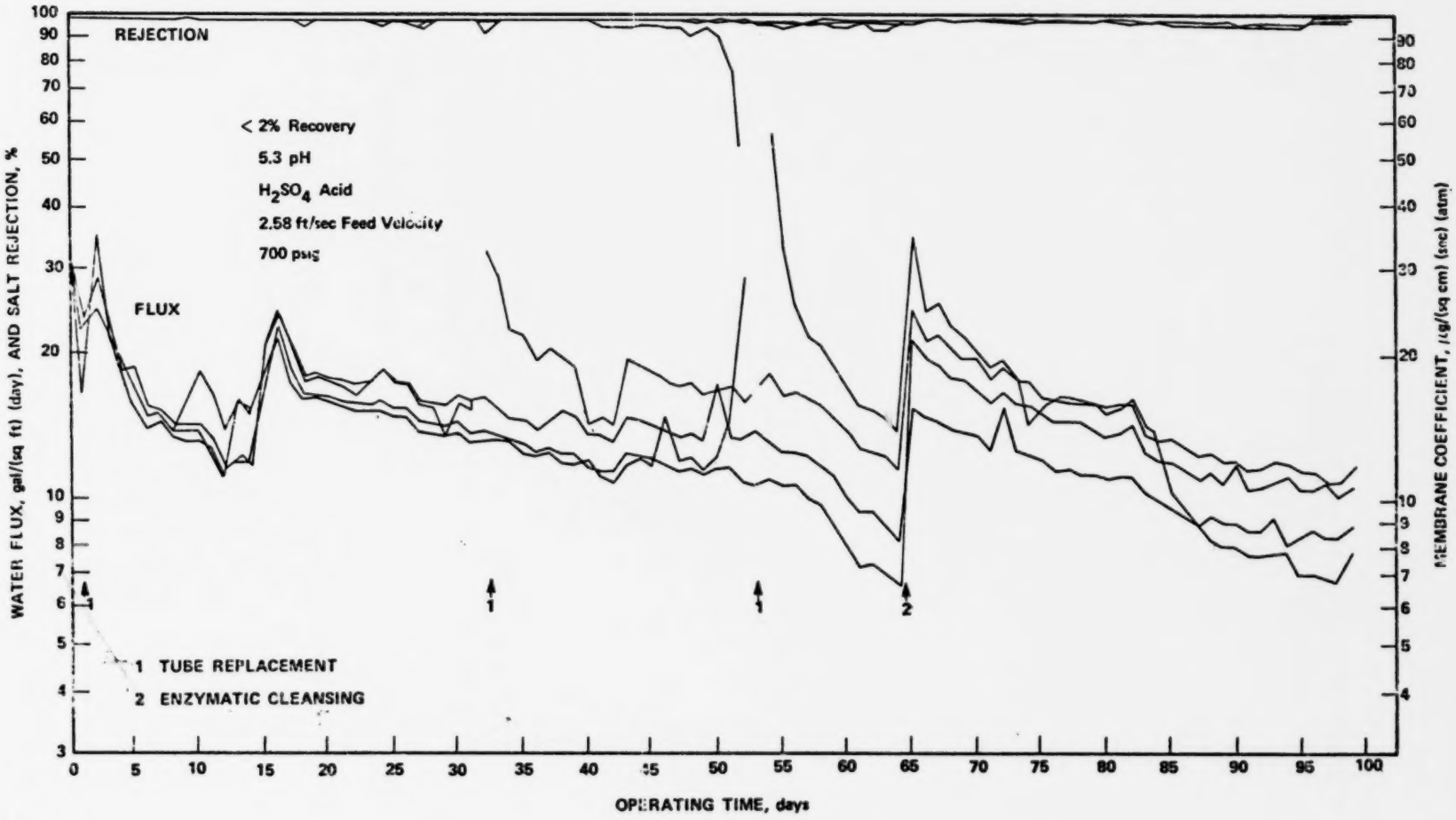

Figure 8. REVERSE OSMOSIS PERFORMANCE WITH SECONDARY EFFLUENT, NONRECIRCULATING SYSTEM

Figure 9 provides a comparison between the product water flux of one tube and daily variations in feed water secondary effluent turbidity, chemical oxygen demand, and electrical conductivity. Cause and effect relationships are difficult to ascertain because variations in flux decline are slight and membrane fouling may easily be influenced by factors other than those presented here. While the increased values for turbidity and dissolved organic matter in late September do correspond to an increase in product water flux decline, other high values for these parameters and total dissolved solids cannot be definitely related to any deviation from the normal flux decline rate.

The average flux increase resulting from daily depressurization of the system for 15 minutes was 4%.

Reference to Table 3 reveals the extremely good rejection characteristics of the reverse osmosis process with secondary effluent. Average rejections for electrical conductivity, chemical oxygen demand, and ammonium nitrogen were 96.9, 94.6, and 90.4%, respectively. The reduction in turbidity was found to be so complete as to provide a product water quality below the accurate sensitivity of the turbidimeter.

An analysis of surface deposits, scraped from a membrane treating secondary effluent, indicated that the solids composition was 0.71% phosphorus, 0.47% calcium, 0.2% sulfate, 94.5% volatile matter, and 4.12 unidentified material. This would indicate that at a product water recovery ratio of 2%, salt precipitate deposition was not a problem, but dissolved and undissolved organic substances did contribute to membrane deposits.

Detailed wastewater constituent rejections and daily product water fluxes with secondary effluent at a low recovery condition may be found in Appendix E.

Concentrated secondary effluent at 80, 70, and 50% product water recovery ratios experienced similarly rapid product water flux declines, as shown in Figure 10. The cause of the observed declines was not ascertained but appear similar in nature to those associated with inorganic salt precipitation. Standard conditions for the concentrated secondary effluent test were identical with the nonrecirculating system except in the use of hydrochloric acid for pH control.

The average recovery of product water flux due to daily system depressurization of 15 minutes was 19.8%. Specific details of membrane performance with concentrated secondary effluent are available in Appendix F.

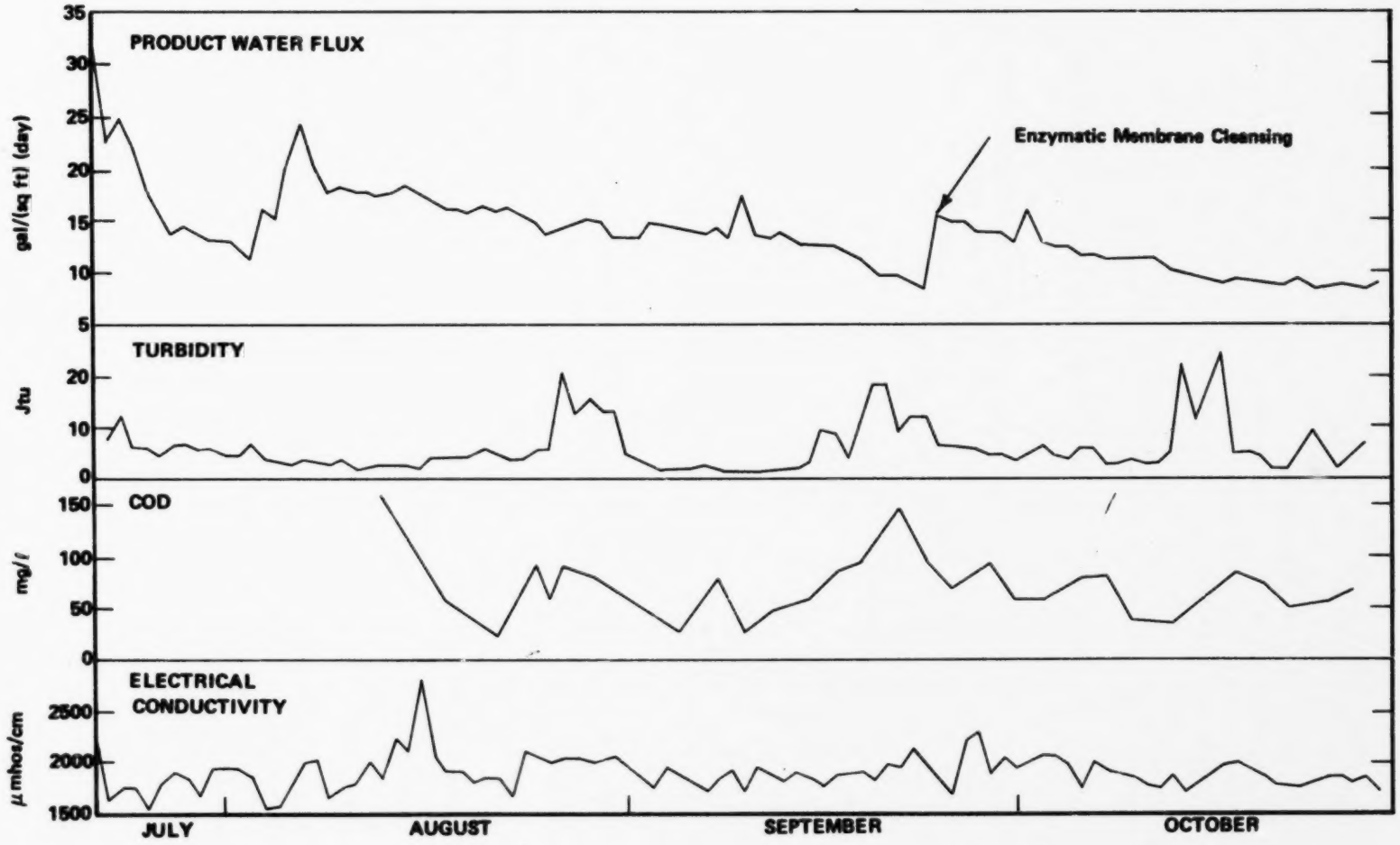

Figure 9. COMPARISON BETWEEN PRODUCT WATER FLUX AND SECONDARY EFFLUENT QUALITY

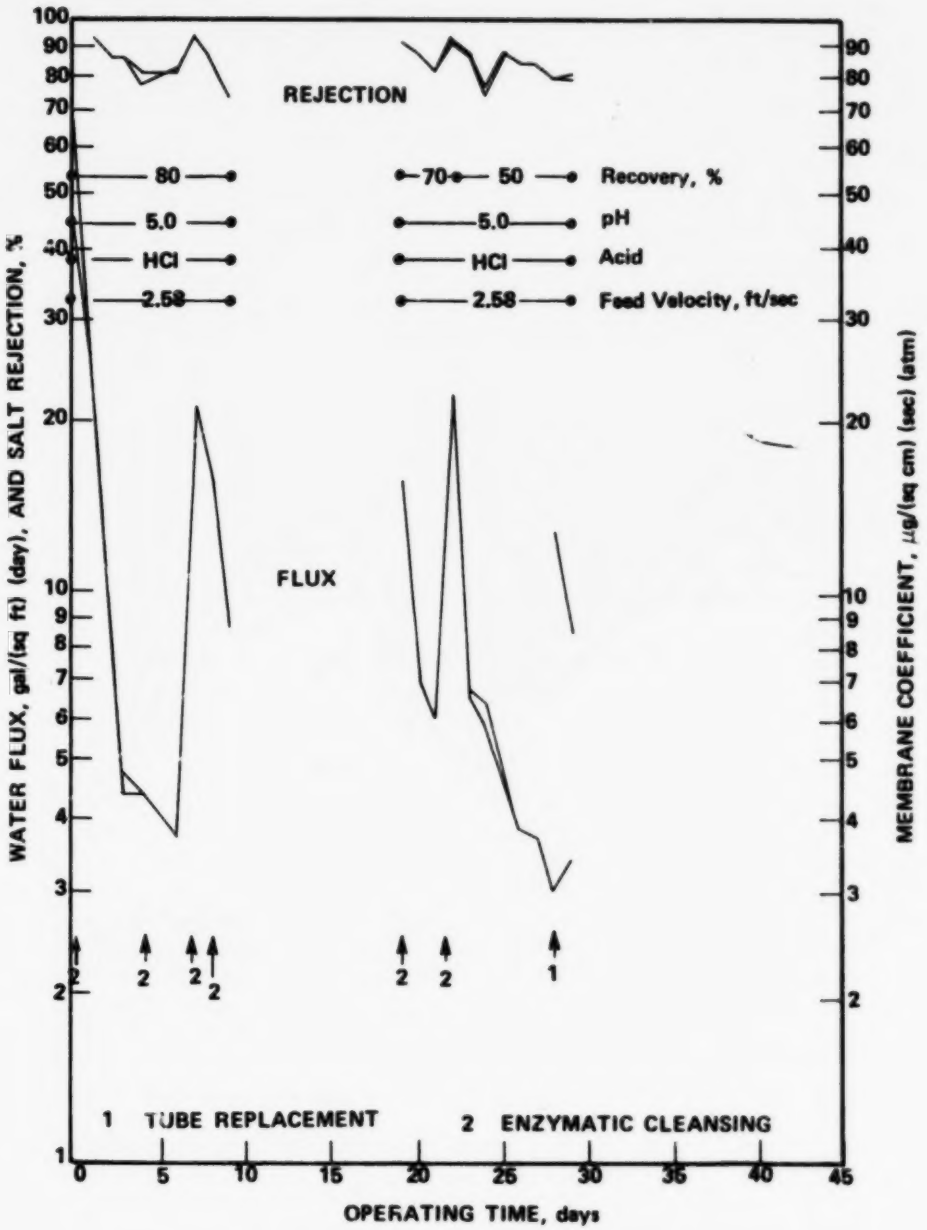

Figure 10. REVERSE OSMOSIS PERFORMANCE WITH CONCENTRATED SECONDARY EFFLUENT, RECIRCULATING SYSTEM AT 700 psig

SECTION V

DISCUSSION

The test program has provided much useful data on a principal obstacle to effective treatment of municipal wastewater by the reverse osmosis process; namely, membrane fouling. Several methods of operation would appear eliminated from further consideration, but one successful method was obtained with primary effluent that could provide a practical means for the treatment of primary effluent by the reverse osmosis process.

The product water flux decline observed upon processing municipal wastewater by reverse osmosis is greatly dependent on the nature of the wastewater constituents. There are three general classes of substances that when deposited on a membrane surface produce a marked reduction in product water flux. These are suspended particulates, ranging in size from settleable matter to finely dispersed colloidal solids; inorganic salt precipitates, created from saturated solutions occurring at or near the membrane surface; and dissolved organic matter, characterized by a very high volatile solids content. There are also sewage constituents, which were not identified by analysis, but which appear to affect membrane performance when no change was discernable in measurements of the aforementioned three classes of foulants. It is nevertheless likely that these unknown foulants, present possibly in the unidentified fractions of analyzed membrane deposits, may be classified under the aforementioned three general categories. Several methods of pretreatment were explored in this program to eliminate or greatly reduce the effects of foulants on reverse osmosis performance.

Suspended and dispersed particulates were controlled by three methods: removal of particulates from the primary effluent feed water stream by chemical flocculation with alum followed by sedimentation and sand filtration, which reduced average feed water turbidities from 61 to 3.8 Jtu; controlling particulate fouling by the use of an anionic polyelectrolyte, Zimmite 190, (previous studies (Ref. 1) had indicated that the polyelectrolyte flocculated dispersed matter into a loose bulky form that would not deposit on the membrane and would be swept away by the bulk wastewater stream); and increase of feed water flows to a maximum value of 10 gpm, corresponding to an axial velocity of 12.9 ft/sec, for hydraulically inducing relatively high turbulent conditions within the tubes.

The precipitation of certain inorganic salts, caused by a saturation of respective salt ions at or near the membrane surface, was reduced or eliminated by adjustment of the hydrogen ion content of the water. Prevention of precipitation of calcium phosphate and calcium carbonate compounds at normal wastewater concentrations is readily accomplished by increasing the hydrogen ion content of the water to a pH of 5. This

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control method is ineffective, however, for calcium sulfate, another common inorganic precipitate. Reductions in concentration of either the calcium or sulfate ion by such means as species removal or decreased concentration polarization at the membrane surface will limit salt deposition on the membrane.

Dissolved organic matter, the third class of foulants, is ordinarily removed by biological treatment. The final product of biological treatment is quite different from a primary effluent that might be subjected only to reduction of dissolved organic substances. Lacking other effective facilities for removing dissolved organics from primary effluent, tests were conducted with secondary effluent, which also is usually characterized by a relatively low suspended solids content.

Periodic cleansing of the membranes is another method of controlling membrane fouling by temporarily restoring product water flux. An enzyme-active laundry presoak formulation was employed in this program as a cleansing agent.

Addition of Zimmite 190 at the dosages employed had no noticeable effect on membrane performance.

A marked improvement in product water flux was observed as axial velocities of primary effluent feed water increased (cf. Figure 5). Comparison of these data with those in Figure 8 reveals a membrane performance for primary sewage very similar to that obtained with secondary effluent at low axial velocities and product water recovery ratios. The feed water axial velocity of 12.9 ft/sec was chosen for study because of the simplicity of manifolding the outputs of two fixed-capacity pumps. It is possible and likely that an intermediate axial velocity between 12.9 and 6.45 ft/sec could provide acceptable product water flux performance. The results obtained at the high feed rate indicate that proper control of hydraulic conditions within the tubular membranes permits retention in the feed stream of all the natural constituents of primary effluent without resort to major pretreatment processes. The turbulence created at high feed water axial velocities reduces the boundary layer at the membrane surface and increases shear forces acting on materials deposited on the membrane, providing a deterrent to most membrane foulants. Similar benefits have been reported by others with pulp mill wastewaters (Ref. 3) and with silt-bearing river water (Ref. 4).

It was shown in Table 3 that increasing feed water axial velocity provides increasingly better product water qualities from primary effluent. This is due to a reduction in liquid boundary layer thickness and concentrations of wastewater constituents immediately adjacent to the membrane surface. At a feed water axial velocity of 12.9 ft/sec with primary effluent, the product water quality closely approached that obtained at 2.58 ft/sec with secondary effluent, which contains generally

lower concentrations of waste constituents. Thus, in situations where recirculation of waste streams is used to maintain minimum hydraulic conditions for prevention of membrane fouling, a reduction in overall product water quality usually results since more membrane area is exposed to more highly concentrated wastewaters. This deterioration in product water quality due to recirculation can be offset by operating at a high feed water axial velocity.

A daily 15-minute discontinuance of feed water flow and reduction to atmospheric pressure within the tubes produced a beneficial effect for all feed water conditions studied. The effectiveness of the depressurization procedure is directly proportional to the extent and rate of solids deposition on the membrane surface. Primary effluent tests experienced flux recoveries immediately after shutdown ranging from 99.4% at 2.58 ft/sec axial velocity to 1.1% at 12.9 ft/sec. Tests with alum-treated, sand-filtered effluent and secondary effluent at 2.58 ft/sec axial velocity underwent flux recoveries of 16.7 and 19.8%, respectively. These recoveries are attributed to a backflow of purified water from the membrane interior created by normal osmotic pressure that loosens deposited materials. Since regular depressurizations appear to produce an increase in product water flux, they should not be overlooked as a possible standard operating procedure.

Removal of suspended matter by alum addition, flocculation, sedimentation, and sand filtration would normally permit an examination of the effects on product water flux decline of sewage constituents that would be overshadowed by gross amounts of particulate matter. However, inorganic salt deposition was a major problem in that substantial flux decline was observed at low product water recovery ratio of less than 2% with alum-treated primary affluent. The analysis of membrane deposits from a test with this feed water subjected to various pH values but no sulfuric acid addition indicated 4.98% sulfate, a high level of sulfate deposition.

The maximum calculated product water ratio was 84% for primary effluent that contained indigenous calcium and sulfate concentrations of 98 mg/l and 181 mg/l, respectively. The addition of alum or sulfuric acid for pH control further reduced allowable product water recovery. It was estimated that the simultaneous use of both chemicals would permit a theoretical maximum product water recovery ratio of 55%. The declines presented in Figure 7 substantiate the inability to maintain product water flux at any appreciable recovery ratio with this feed water.

It is conceivable that deposits on the membrane surface from wastewaters produce a concentration polarization much higher than is commonly associated with unfouled membranes. It would seem, therefore, that alum treatment of a high-sulfate content sewage for removal of membrane foulants would have limited application under the standard operating conditions of this program.

An alternative pretreatment process that may be of use and should be studied further is clarification of the primary effluent with lime. Not only does lime flocculate disperse particulates, but, unlike aluminum sulfate, it also lowers the calcium content of the sewage, reducing opportunities for calcium sulfate salt precipitation. Lime has the added advantage of not introducing sulfates to the water and may itself be recovered for future reuse. Clarification with lime results in an increased feed water pH, but inasmuch as pH adjustment downward may be indicated in any event for the reverse osmosis process, and since lime clarification reduces the alkalinity of the feed water, the amount of acid required may be little affected.

The occasional indications of salt precipitation on membrane surfaces at low product water recovery ratios may also have been due to transient high concentrations of inorganic species in the wastewater from the City of Corona. During the very early hours of the morning, extremely high levels of calcium and magnesium are present in the sewage as the result of automatic regeneration operations of numerous domestic ion exchange water softeners. Water Reclamation Plant records indicate that the measured peak levels of sewage constituents arising from the regenerating operations occur at 0500 hours and are 3,900 μmhos/cm electrical conductivity, 1,275 mg/l chloride, and 650 mg/l total hardness. By 0800 hours the levels have dropped to 1,500 μmhos/cm electrical conductivity, 175 mg/l chloride, and 230 mg/l total hardness. From 1100 hours until early the next morning these constituents maintain a steady level of 1,300 μmhos/cm electrical conductivity, 175 mg/l chloride, and 230 mg/l total hardness. It is evident that the nonrecirculating, low recovery reverse osmosis systems were subjected daily to short-term, high levels of potentially damaging inorganic salt concentrations, which were not evident in grab samples taken for analysis or for recirculating system feed water during a standard working day.

The product water flux decline associated with a membrane fouled primarily with dissolved organic matter, which was shown in Figure 8, reveals that dissolved organics have a lesser effect than do suspended particulates or precipitating inorganic salts. The moderate flux decline achieved with a secondary effluent adjusted only for pH level would tend to indicate that successful operation of a large-scale reverse osmosis plant treating secondary effluent may be achieved by intermittent cleansing of the membranes to restore product water flux to acceptable levels. However, rapid flux declines were experienced at 50, 70, and 80% product water ratios due presumably to inorganic salt precipitation. Inability to operate at any appreciable recovery level with this particular feed water due to salt precipitation limits its use in the reverse osmosis process under the standard test conditions encountered at the City of Corona. There are many locations and applications, however, that would not be limited by dissolved salts in the feed water.

Lesser amounts of calcium sulfate deposits, and attendant higher product water fluxes, occurred with secondary effluent dosed with sulfuric acid than with primary effluent dosed with sulfuric acid, even though the same concentrations of calcium and sulfate existed in both sewages. The difference is attributed to the degree of membrane fouling caused by suspended matter and organic substances in the sewages. Relatively heavy fouling by these materials with primary effluent feed water retards to a greater extent the back diffusion of inorganic salts from the membrane surface, resulting in higher salt concentrations and a more saturated condition than is experienced by the relatively light membrane fouling with secondary effluent.

Membrane rejuvenation by cleansing with an enzyme-active laundry presoak formulation proved beneficial for both primary and secondary effluents where the principal causes of fouling were suspended and dissolved organic matter. The cleansing procedure was also of value in removing inorganic salt precipitates as in the case of the test with alum-treated, sand-filtered primary effluent, where numerous cleansings were performed in an effort to maintain product water flux during high product water recovery conditions.

Occasionally, the entire series of tubes in a single test experienced a simultaneous rejuvenation in product water flux. This occurred with secondary effluent after 15 days of operation (cf. Figure 8) and primary effluent at a 6.45 ft/sec axial velocity after 2 days of operation (cf. Figure 5). This unusual performance could not be attributed to irregular operating procedures or technical difficulties with the test equipment. It is quite possible that some unknown characteristics of the feed water was directly responsible for inhibition of product water flux. The action may be due to a cleansing effect of some constituent that was intermittently present in the feed water or some substance previously deposited on the membrane that lost its adhesiveness to the membrane surface. Unexplained results such as these point out that even while reverse osmosis may now be used to treat wastewater, a great deal of information is lacking about all the factors influencing this process.

SECTION VI

ACKNOWLEDGMENTS

The 6-month program was performed by the Envirogenics Company, a Division of Aerojet-General Corporation, at El Monte, California, under the direction of Mr. Gerald Stern, Project Officer, Water Quality Office. Envirogenics Company personnel participating in the program were Dr. D. L. Feuerstein, Program Manager; Mr. T. A. Bursztynsky, Project Engineer; Messrs. H. Barnard and R. Nygren, Laboratory Technicians; and Mrs. M. D. Robinson, Secretary.

The complete cooperation of Mr. Arthur E. Goulet, Director of Public Works, Mr. Gilbert Cleveland, Superintendent of Water Pollution Control, and the staff at the Water Reclamation Plant of the City of Corona, California, in providing a site for the study and very helpful assistance to this program is gratefully appreciated and acknowledged.

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SECTION VII

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SECTION VIII

GLOSSARY

BOD - Biochemical Oxygen Demand. By means of a standardized laboratory procedure, an indication of the concentration of chemical species that can be oxidized by micro-organisms is derived.

Coagulation - The mutual attraction and coalescence of oppositely charged colloids to produce a (usually gelatinous) precipitated phase. In water treatment, the addition and subsequent hydration of oxides of aluminum or iron produce positively charged colloids which can be used to remove negatively charged organic colloids.

COD - Chemical Oxygen Demand. By means of a standardized laboratory procedure, an indication of the concentration of chemical species that can be chemically oxidized is derived.

Electrical Conductivity - Also called Conductance, this Ohmic property defines the ability of a solution to pass current and is expressed as the reciprocal of resistance. Its magritude is determined by the nature and concentrations of the ions present.

Flocculation - Small, coagulated particles become accreted to form larger, more precipitable structures. This process is promoted through the use of chemical coagulants, adjustment of the physical or chemical condition of the system, or, biologically, through micro-organism growth and activity.

Polyelectrolyte - A synthetic or natural polymeric material in which the monomeric unit features an ionizable group. Depending on the nature of the latter, a polyelectrolyte may be cationic, anionic, or amphoteric (e.g., proteins). When dispersed, such materials can undergo coagulation with oppositely charged colloids.

Primary Effluent - The product water resulting from the primary sewage treatment process, which consists of screening, grease and scum removal, and sedimentation.

Product Water Flux - The rate of flow of water passing through a unit area of reverse osmosis membrane under specified conditions of pressure, temperature, and feed water solution composition (typically, gal. /sq ft-day).

Product Water Flux Decline - The inherent property of reverse osmosis membranes to experience permeability loss under fixed operating conditions. Flux decline rate is dependent on flux level, boundary layer conditions, Reynolds number, and other system properties.

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Reverse Osmosis - A separation technique where application of pressure greater than the solution osmotic pressure causes relatively pure water to pass through a membrane.

Reynolds Number - A dimensionless number proportional to the ratio of internal force to viscous force in a flow system, whose value is indicative of the degree of turbulence of the fluid.

Sand Filtration - The process of removing coagulated solids within a thick column of sand, wherein such particles become lodged and aggregated in the interstitial spaces of the bed channels. Filter rejuvenation is usually accomplished by turbulent back washing.

Secondary Effluent - The product water resulting from the secondary sewage treatment process, which consists of some form of biological assimilation and degradation of primary effluent plus sedimentation.

SECTION IX

APPENDICES

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Appendix A

INITIAL OSMOTIC PROPERTIES OF REVERSE OSMOSIS MEMBRANES

Production Line Quality-Control Test

Tube Designation	Water Flux, gal/(sq ft)(day)	Salt Rejection, %
78-II	37.6	88.7
82-I	36.6	87.2
87-I	37.9	89.1
93-I	34.4	81.8
77-II	34.4	81.8
81-III	29.9	90.1
191-I	26.8	89.9
86-II	30.2	86.7
67-I	39.1	83.7
172-I	29.0	86.5
83-II	31.8	87.7
184-I	29.0	88.4
84-I	39.1	88.7
70-IV	31.8	86.8
74-II	36.9	90.7
88-I	32.6	91.2
69-I	42.9	82.4
163-II	35.8	84.4

Appendix A (Continued)

INITIAL OSMOTIC PROPERTIES OF REVERSE OSMOSIS MEMBRANES

Production Line Quality-Control Test

Tube Designation	Water Flux, gal/(sq ft)(day)	Salt Rejection, %
115-II	22.3	85.9
167-II	31.4	85.2
98-II	39.8	89.3
185-I	45.0	85.7
106-I	27.3	90.8
165-II	22.3	85.9
242-I	31.9	89.2
99-II	36.4	86.2
171-II	29.0	88.1
285-I	36.6	85.0
287-I	36.6	80.5
293-III	39.8	84.5
294-II	34.8	88.7
288-I	31.0	88.1
300-III	34.8	88.9
281-I	28.5	89.2
301-IV	31.0	95.4

Appendix B

PERFORMANCE AND WATER QUALITY CHARACTERISTICS, ZIMMITE 190-TREATED PRIMARY EFFLUENT, NONRECIRCULATING SYSTEM (700 psig, 2% Recovery)

Date	FEED WATER									PRODUCT WATER									
	Axial Vel. ft/sec	pH	Acid Feed	Zim. 190 mg/l	Temp. °C	EC	COD mg/l	NH_3-N mg/l	Turbidity Jtu	Flux, gal/(sq ft)(day)				EC, μmhos/cm				COD mg/l	NH_3-N mg/l
										1	2	3	4	1	2	3	4	1 - 4	1 - 4
11 Aug 70	2.58	6.0	H_2SO_4	2	33	1950	-	-	48	40[a]	41.9[b]	44.4[c]	40.3[d]	70[a]	86[b]	91[c]	78[d]	-	-
12 Aug 70	2.58	6.0	H_2SO_4	2	33	1590	-	-	64	5.5	5.6	5.6	5.5	95	112	126	102	-	-
13 Aug 70*	2.58	6.0	H_2SO_4	2	31	1800	389	-	-	10.5	10.6	11.2	10.8	58	71	180	67	-	-
14 Aug 70*	2.58	6.0	H_2SO_4	2	34	2250	-	-	-	11.2	11.6	10.8	10.8	50	46	70	46	-	-
		Pump Repair																	
18 Aug 70	2.58	5.9	H_2SO_4	2	35	1950	268	-	53	10.3[e]	9.4[f]	11.4[g]	8.7[h]	136[e]	125[f]	80[g]	76[h]	8.6	-
19 Aug 70	2.58	6.0	H_2SO_4	2	36	1700	-	-	64	3.0	3.0	2.8	3.6	304	228	154	155	-	-
20 Aug 70*	2.58	6.0	H_2SO_4	2	31	1900	-	-	51	15.9	9.5	16.7	16.7	55	62	52	42	-	-
21 Aug 70	2.58	6.0	H_2SO_4	2	30	1750	-	-	-	8.8	5.9	8.4	8.3	126	90	146	54	-	-
22 Aug 70	2.58	6.0	H_2SO_4	2	31	1950	54	-	49	17.7	3.7	4.3	3.7	67	160	142	77	17.5	-
23 Aug 70*	2.58	6.1	H_2SO_4	2	30	2100	-	-	44	22.4	4.7	6.5	6.3	59	75	150	60	-	-
24 Aug 70	2.58	6.1	H_2SO_4	2	31	1900	-	-	67	6.6	2.6	2.9	3.0	84	190	392	84	-	-
25 Aug 70*	2.58	6.1	H_2SO_4	0	32	2000	248	1.5	49	21.1	7.0	18.9[i]	18.1	51	102	99[i]	47	19.2	0.5
26 Aug 70	2.58	6.0	H_2SO_4	0	32	1800	226	-	47	14.7	9.6[j]	13.7	11.7	74	70[j]	132	40	25.8	-
27 Aug 70	2.58	6.0	H_2SO_4	0	32	2000	296	3.5	58	8.1	6.7	8.3	8.9	71	73	100	44	5.98	0.65
28 Aug 70	2.58	6.0	H_2SO_4	0	31	1950	-	-	60	3.0	2.9	3.0	4.8	122	146	186	55	-	-
29 Aug 70*	2.58	6.1	H_2SO_4	0	30	2100	203	-	58	6.7	14.4	4.4	10.0	89	53	130	44	13.3	-
30 Aug 70	2.58	6.2	H_2SO_4	0	30	2100	-	-	48	3.9	4.8	3.3	4.4	116	94	143	74	-	-
31 Aug 70*	2.58	6.0	H_2SO_4	1	32	1850	-	-	66	8.8	11.7	6.7	11.4	60	49	110	54	-	-

[a]Tube 81-III; [b]Tube 86-II; [c]Tube 172-I; [d]Tube 185-I; [e]Tube 191-I; [f]Tube 67-I; [g]Tube 83-II; [h]Tube 184-I; [i]Tube 185-I; [j]Tube 171-II

*Enzymatic Cleansing

Appendix B (Continued)
PERFORMANCE AND WATER QUALITY CHARACTERISTICS,
ZIMMITE 190-TREATED PRIMARY EFFLUENT,
NONRECIRCULATING SYSTEM (700 psig, 2% Recovery)

Date	FEED WATER									PRODUCT WATER.									
	Axial Vel. ft/sec	pH	Acid Feed	Zim. 190 mg/l	Temp °C	EC	COD mg/l	NH_3-N mg/l	Turbidity Jtu	Flux, gal/(sq ft)(day)				EC, μmhos/cm				COD mg/l	NH_3-N mg/l
										1	2	3	4	1	2	3	4	1 - 4	1 - 4
1 Sep 70	2.58	6.0	H_2SO_4	1	32	1925	-	-	52	10.4	14.3	3.8	5.6	60	49	110	54	-	-
2 Sep 70	2.58	-	H_2SO_4	1	-	-	-	-	-	4.8	8.6	-	-	-	-	-	-	-	-
3 Sep 70	2.58	6.3	H_2SO_4	1	33	2000	186	3.5	55	4.1	12.0	-	-	142	-	-	-	6.5	0.5
4 Sep 70*	2.58	5.9	H_2SO_4	4	32	1850	-	-	58	20.0[k]	35.6[l]	17.5[m]	26.9[n]	72[k]	65[l]	54[m]	36[n]	-	-
5 Sep 70	2.58	6.0	H_2SO_4	4	31	2100	104	-	73	10.4	4.8	9.6	11.9	90	260	70	69	6.4	-
6 Sep 70	2.58	6.1	H_2SO_4	4	33	1975	-	-	58	3.8	3.4	3.3	3.9	215	405	178	203	-	-
7 Sep 70*	2.58	6.1	H_2SO_4	4	33	1840	-	-	-	2.8	2.7	2.7	2.8	244	500	212	222	-	-
8 Sep 70*	2.58	6.0	H_2SO_4	4	36	2080	179	-	72	-	-	-	-	-	--	237	260	37	-
9 Sep 70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10 Sep 70*	2.58	-	HCl	2	-	-	-	-	--	-	-	20.0[o]	41.6	-	-	-[o]	-	-	-
11 Sep 70	2.58	6.1	HCl	2	34	1900	-	-	57	-	-	7.8	7.4	-	-	92	190	-	-
12 Sep 70	2.58	6.5	HCl	2	31	1850	-	-	63	-	-	3.3	3.6	-	-	155	240	-	-
13 Sep 70*	2.58	5.7	HCl	0	33	2425	-	-	64	-	-	2.3	2.3	-	-	250	480	-	-
14 Sep 70	2.58	-	HCl	0	-	-	-	-	-	-	-	21.8[p]	22.3[q]	-	-	-[p]	-[q]	-	-
15 Sep 70*	2.58	5.1	HCl	0	32	2050	246	-	73	-	-	4.1	4.7	-	-	40	38	14.6	-
16 Sep 70	6.45	6.2	H_2SO_4	2	31	1850	-	3.8	65	-	-	12.6	13.0	-	-	78	55	-	0.4
17 Sep 70	6.45	6.2	H_2SO_4	2	32	1975	275	-	73	-	-	5.0	5.0	-	-	114	92	15.4	-
18 Sep 70	6.45	6.2	H_2SO_4	2	31	1760	-	-	54	-	-	7.1	7.1	-	-	75	57	-	-

[k]Tube 185-I; [l]Tube 167-II; [m]Tube 191-I; [n]Tube 171-II; [o]Tube 167-II; [p]Tube 285-I; [q]Tube 286-I

*Enzymatic Cleansing

Appendix B (Continued)

PERFORMANCE AND WATER QUALITY CHARACTERISTICS
ZIMMITE 190-TREATED PRIMARY EFFLUENT.
NONRECIRCULATING SYSTEM(700 psig, 2% Recovery)

Date	FEED WATER									PRODUCT WATER									
	Axial Vel. ft/sec	pH	Acid Feed	Zim. 190 mg/l	Temp. °C	EC	COD mg/l	NH_3-N mg/l	Turbidity Jtu	Flux, gal/(sq ft)(day)				EC, μmhos/cm				COD mg/l	NH_3-N mg/l
										1	2	3	4	1	2	3	4	1 - 4	1 - 4
19 Sep 70	6.45	6.2	H_2SO_4	2	32	1700	217	-	63	-	-	14.2	17.5	-	-	64	45	217	-
20 Sep 70	6.45	6.3	H_2SO_4	2	31	2125	-	-	57	-	-	4.7	5.6	-	-	136	84	-	-
21 Sep 70	6.45	6.2	H_2SO_4	2	31	1925	-	-	54	-	-	3.3	3.4	-	-	122	93	-	-
22 Sep 70*	2.58	6.0	HCl	2	32	1700	218	-	47	-	-	14.7	15.4	-	-	136	116	218	-
23 Sep 70	2.58	5.8	HCl	2	34	2150	-	7.5	83	-	-	2.8	3.0	-	-	202	134	-	7.5
24 Sep 70*	2.58	5.4	HCl	2	33	2175	376	-	56	-	-	28.8	27.8	-	-	178	150	376	-
25 Sep 70	2.58	3.5	HCl	2	33	1950	-	-	65	-	-	16.6	17.0	-	-	50	42	-	-
26 Sep 70	2.58	5.8	HCl	2	33	1900	250	-	71	-	-	5.5	5.6	-	-	84	75	250	-
27 Sep 70	2.58	4.8	HCl	2	34	2475	-	-	73	-	-	8.3	8.5	-	-	69	60	-	-
28 Sep 70	2.58	4.6	HCl	2	34	2275	-	-	86	-	-	3.9	3.8	-	-	144	90	-	-
29 Sep 70*	12.9	5.7	H_2SO_4	0	31	2100	317	-	72	51[r]	52[s]	30.2	27.4	50[r]	50[s]	37	31	317	-
30 Sep 70	12.9	5.5	H_2SO_4	0	31	1925	-	-	62	27.2	26.3	20.6	19.4	32	31	24	22	-	-
1 Oct 70	12.9	5	H_2SO_4	0	32	1875	261	-	87	23.4	27.8[t]	19.0	17.8	85	67[t]	36	25	6.7	-
2 Oct 70	12.9	5	H_2SO_4	0	33	1800	-	-	72	25.8	30.0	21.2	20.4	60	51	29	23	-	-
3 Oct 70	12.9	5.4	H_2SO_4	0	32	1750	185	-	90	24.1	27.5	20.6	19.7	63	45	25	21.5	9.3	-
4 Oct 70	12.9	5.8	H_2SO_4	0	32	2050	-	-	74	23.2	24.7	29[u]	19.4	53	44	26[u]	22	-	-
5 Oct 70	12.9	5.2	H_2SO_4	0	31	2800	-	-	100	20.8	28.8[v]	45.2[w]	17.5	108	78[v]	1300[w]	116	-	-
6 Oct 70	12.9	5	H_2SO_4	0	-	1600	-	-	-	25.6	47[x]	45.5[y]	20.6	100	75[x]	65[y]	44	-	-
7 Oct 70	12.9	5.4	H_2SO_4	0	30	1650	-	-	82	16.3[z]	31.9[aa]	25.6	17.5	16[z]	39[aa]	27	20		

[r]Tube 288-I; [s]Tube 242-I; [t]Tube 287-I; [u]Tube 191-I; [v]Tube 171-II; [w]Tube 99-II; [x]Tube 293-III; [y]Tube 302-III; [z]Tube 281-I; [aa]Tube 300-III.

*Enzymatic Cleansing

Appendix B (Continued)

PERFORMANCE AND WATER QUALITY CHARACTERISTICS
ZIMMITE 190-TREATED PRIMARY EFFLUENT,
NONRECIRCULATING SYSTEM (700 psig, 2% Recovery)

Date	FEED WATER									PRODUCT WATER									
	Axial Vel. ft/sec	pH	Acid Feed	Zim. 190 mg/l	Temp. °C	EC	COD mg/l	NH_3-N mg/l	Turbidity Jtu	Flux, gal/(sq ft)(day)				EC, μmhos/cm				COD mg/l	NH_3-N mg/l
										1	2	3	4	1	2	3	4	1 - 4	1 - 4
8 Oct 70	12.9	5.7	H_2SO_4	0	31	2100	349	-	62	21.0	23.4	24.0	17.5	90	33	25	21	8.7	-
9 Oct 70	12.9	5.6	H_2SO_4	0	30	1950	-	-	55	37.0[bb]	33.7[cc]	23.8	17.9	44[bb]	35[cc]	22	20	-	-
10 Oct 70	12.9	5.9	H_2SO_4	0	30	1750	194	-	70	27.5	24.1	24.1	18.4	37	25	22	20	0	-
11 Oct 70	12.9	5	H_2SO_4	0	30	2200	-	-	42	25.6	22.2	23.1	17.8	36	22	24	24	-	-
12 Oct 70	12.9	4	H_2SO_4	0	30	2050	-	-	66	19.2	17.3	18.8	15.6	30	18	18	16	-	-
13 Oct 70	12.9	4	H_2SO_4	0	29	1950	161	-	61	17.5	15.4	17.1	14.4	31	22	24	22	2.2	-
14 Oct 70	12.9	4.5	H_2SO_4	0	30	2100	-	-	65	17.7	10.0[dd]	17.1	14.0	33	70[dd]	29	23	-	-

[bb]Tube 304-III; [cc]Tube 301-IV; [dd]Tube 290-I

Appendix C
PERFORMANCE AND WATER QUALITY CHARACTERISTICS ALUM-TREATED, SAND-FILTERED PRIMARY EFFLUENT, NONRECIRCULATING SYSTEM

(700 psig, 2% Recovery, 2.58 ft/sec Axial Velocity)

Date	FEED WATER								PRODUCT WATER									
	Cl_2 mg/l	pH	Acid Feed	Temp. °C	EC	COD mg/l	NH_3-N mg/l	Turbidity Jtu	Flux, gal/(sq ft)(day)				EC, μmhos/cm				COD mg/l	NH_3-N mg/l
									1	2	3	4	1	2	3	4	1 - 4	1 - 4
6 Aug 70	0	5.6	H_2SO_4	32	2150	-	-	7.3	45.2[a]	41.2[b]	40.2[c]	35.8[d]	250	106	73	252	-	-
7 Aug 70	0	-	H_2SO_4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8 Aug 70	0	5.7	H_2SO_4	35	2750	-	-	15	-	-	-	-	940	142	88	840	-	-
9 Aug 70	0	6.2	H_2SO_4	30	1850	-	-	3.8	19.7	22.8	21.8	23.0	252	49	46	180	-	-
10 Aug 70	0	6.0	H_2SO_4	32	2040	-	-	1.7	16.3	11.7	11.7	14.0	975	74	88	254	-	-
11 Aug 70	0	5.2	H_2SO_4	31	2000	-	-	2.4	40.4[e]	38.4[f]	28.2	29.0[g]	72[e]	66[f]	49	62[g]	-	-
12 Aug 70	0	5.5	H_2SO_4	34	1925	-	-	1.4	13.1	16.2	12.1	11.7	71	64	51	63	-	-
13 Aug 70	0	6.5	H_2SO_4	34	2200	117	-	1.6	10.5	12.0	10.4	10.4	86	72	58	74	-	-
14 Aug 70	0	6.0	H_2SO_4	38	2450	-	-	-	7.8	8.7	8.4	8.1	106	91	73	82	-	-
15 Aug 70	0	5.4	H_2SO_4	40	2250	-	-	3.5	6.6	5.6	6.3	5.6	460	132	80	120	-	-
16 Aug 70	0	5.0	H_2SO_4	34	2250	-	-	1.7	5.4	4.8	4.9	4.7	520	158	100	120	-	-
17 Aug 70	0	5.2	H_2SO_4	33	-	-	-	-	5.0	4.1	4.4	4.2	560	173	104	122	-	-
18 Aug 70*	0	5.6	H_2SO_4	36	2350	105	-	1.0	15.5	8.6	28.0	29.8	730	140	1260	1650	21.9	-
4 Sep 70	0	6.1	none	-	1820	-	-	1.8	79[h]	70[i]	66[j]	61[k]	360[h]	860[i]	590[j]	860[k]	-	-
5 Sep 70	0	6.8	none	33	2350	54	-	1.3	21.2	20.6	20.6	17.2	140	142	245	180	0.9	-
6 Sep 70	0	6.4	none	34	2000	-	-	1.1	23.4	23.4	23.1	23.4	103	100	235	165	-	-
7 Sep 70	0	6.3	none	34	2300	-	-	0.8	17.0	16.8	23.0	17.0	171	145	800	165	-	-
8 Sep 70	0	6.6	none	36	2275	60	-	0.8	33.5	29.2	19.2	14.3	77	82	506	220	7.9	-
9 Sep 70	0	6.6	none	34	2140	-	4.8	6.9	35.4	35.1	34.4[l]	27.3[m]	245	180	195[l]	80[m]	-	0.4

[a]Tube 84-I; [b]Tube 74-II; [c]Tube 88-I; [d]Tube 69-I; [e]Tube 70-IV; [f]Tube 171-II; [g]Tube 74-II; [h]Tube 165-II; [i]Tube 99-II; [j]Tube 163-II; [k]Tube 163-II; [k]Tube 115-II; [l]Tube 115-II; [m]Tube 185-I.

*Enzymatic Cleansing.

Appendix C (Continued)
PERFORMANCE AND WATER QUALITY CHARACTERISTICS
ALUM-TREATED, SAND-FILTERED PRIMARY EFFLUENT,
NONRECIRCULATING SYSTEM
(700 psig, 2% Recovery, 2.58 ft/sec Axial Velocity)

Date	FEED WATER								PRODUCT WATER									
	Cl_2 mg/l	pH	Acid Feed	Temp. °C	EC	COD mg/l	NH_3-N mg/l	Turbidity Jtu	Flux, gal/(sq ft)(day)				EC, μmhos/cm				COD mg/l	NH_3-N mg/l
									1	2	3	4	1	2	3	4	1 - 4	1 - 4
10 Sep 70	0	6.6	none	36	2150	76	-	6.6	31.2	20.9	22.1	24.6	110	167	162	155	7.0	-
11 Sep 70	0	6.9	none	35	2100	-	-	1.8	30.6	18.1	20.0	25.3	94	180	122	130	-	-
12 Sep 70	0	6.5	none	32	2050	66	-	7.7	19.1	14.6	15.3	21.6	155	208	150	132	7.8	-
13 Sep 70	0	6.4	none	32	2300	-	-	1.1	12.3	11.1	11.2	17.1	129	155	129	62	-	-
14 Sep 70**	0	6.3	none	34	2040	-	-	1.0	9.6	9.6	61.5[n]	19.3	140	170	168[n]	146	-	-
15 Sep 70	0	6.6	none	34	2090	105	-	8.2	6.1	6.9	9.2	9.1	193	300	200	165	29.1	-
16 Sep 70**	4	6.3	none	34	2300	-	1.5	3.9	32.7	30.8	38.8	17.5	118	96	98	76	-	0.4
17 Sep 70	4	6.4	none	35	2250	111	-	9.6	20.2	20.4	20.7	15.2	106	69	68	41	32.3	-
18 Sep 70	4	6.1	none	33	1900	-	-	3.7	15.0	15.4	15.0	13.5	99	82	88	46	-	-
19 Sep 70	4	6.2	none	34	2100	60	-	5.2	18.1	18.7	16.5	29.0[o]	114	133	141	124[o]	17.1	-
20 Sep 70	4	6.2	none	33	2000	-	-	2.3	16.0	18.5	14.2	25.2	128	96	104	84	-	-
21 Sep 70*	4	6.1	none	34	2125	-	-	1.7	11.9	13.4	10.9	13.6	116	93	108	112	-	-
22 Sep 70	4	6.0	none	34	2080	84	-	2.5	11.0	12.1	10.0	13.7	96	96	105	88	6.0	-
23 Sep 70	4	4.0	none	35	2300	-	4.4	1.6	9.2	10.0	8.9	10.9	168	132	148	143	-	0.5
24 Sep 70	0	5.2	none	34	2150	59	-	1.3	8.4	9.1	8.1	10.3	104	92	122	104	5.3	-
25 Sep 70	0	5.2	HCl	35	2290	-	-	8.4	11.0	11.0	9.2	17.9	138	113	143	80	-	-
26 Sep 70	0	5.5	HCl	35	2200	63	-	6.6	8.6	8.4	7.5	10.8	180	160	210	190	3.8	-
27 Sep 70	0	5.1	HCl	36	2600	-	-	3.8	8.3	8.1	9.2	9.4	200	180	225	282	-	-
28 Sep 70	0	5.0	HCl	35	2500	-	-	2.4	9.4	7.4	6.9	7.8	126	155	198	250	-	-

[n] Tube 290-I; [o] Tube 281-I

* Enzymatic Cleansing

** 30 mg/l Chlorine Wash

Appendix D

PERFORMANCE AND WATER QUALITY CHARACTERISTICS
ALUM-TREATED, SAND-FILTERED PRIMARY EFFLUENT,
RECIRCULATING SYSTEM, (700 psig)

Date	FEED WATER									PRODUCT WATER									
	Recovery %	Axial Vel. ft/sec	pH	Acid Feed	Temp. °C	EC	COD mg/l	NH_3-N mg/l	Turbidity Jtu	Flux, gal/(sq ft)(day)				EC, μmhos/cm				COD mg/l	NH_3-N mg/l
										1	2	3	4	1	2	3	4	1 - 4	1 - 4
12 Aug 70	90	2.58	5.1	H_2SO_4	33	6800	-	-	5.1	46.8[a]	46[b]			185[a]	215[b]			-	-
13 Aug 70	90	2.58	5.5	H_2SO_4	34	9000	127	-	1.5	6.1	5.1			440	480			-	-
14 Aug 70*	90	2.58	5.5	H_2SO_4	35	10000	-	-	-	38.3	38.3			380	402			-	-
15 Aug 70*	90	2.58	5.3	H_2SO_4	40	10000	-	-	-	36.0	36.0			380	385			27.1	-
16 Aug 70*	90	2.58	5.6	H_2SO_4	36	10600	-	-	7.8	12.3	9.6			580	440			-	-
17 Aug 70*	90	2.58	4.9	H_2SO_4	35	10000	-	-	-	25.0	25.5			500	455			-	-
9 Sep 70	65	1.29	7.2	none	31	4400	-	4.8	-	30.6[c]	27.2[d]			165[c]	170[d]			-	0.2
10 Sep 70	65	1.29	7.1	none	36	4800	202	-	9.2	14.5	14.4			150	212			10.6	-
11 Sep 70	65	1.29	7.4	none	38	4800	-	-	5.8	10.6	11.0			235	240			-	-
12 Sep 70	65	1.29	7.3	none	37	4900	198	-	4.3	9.7	9.4			295	330			10.6	-
13 Sep 70	65	1.29	7.4	none	34	5000	-	-	1.4	-	-			225	250			-	-
14 Sep 70	65	1.29	7.2	none	34	4100	-	-	1.0	8.9	9.1			190	205			-	-
15 Sep 70	65	1.29	7.4	none	34	6900	278	-	1.0	8.1	8.4			365	355			6.0	-
16 Sep 70	65	1.29	6.0	HCl	35	5200	-	8.0	4.6	8.5	8.6			307	260			-	1.0
17 Sep 70	65	1.29	4.7	HCl	35	5400	254	-	2.1	43.5[e]	9.6			352[e]	250			54	-
18 Sep 70	65	1.29	5.3	HCl	35	5000	-	-	2.6	17.3	7.3			340	310			-	-
19 Sep 70	65	1.29	5.7	HCl	33	4200	170	-	5.8	13.3	6.9			235	210			18	-
20 Sep 70	65	1.29	5.2	HCl	33	4900	-	-	2.1	12.5	6.6			290	275			-	-
21 Sep 70	65	1.29	5.7	HCl	33	5000	-	-	0.5	11.2	6.1			250	300			-	-

[a]Tube 184-I; [b]Tube 83-II; [c]Tube 98-II; [d]Tube 106-I; [e]Tube 287-I.

*Enzymatic Cleansing.

Appendix D (Continued)
PERFORMANCE AND WATER QUALITY CHARACTERISTICS
ALUM-TREATED, SAND-FILTERED PRIMARY EFFLUENT,
RECIRCULATING SYSTEM, (700 psig)

Date	FEED WATER									PRODUCT WATER									
	Recovery %	Axial Vel. ft/sec	pH	Acid Feed	Temp. °C	EC	COD mg/l	NH_3-N mg/l	Turbidity Jtu	Flux, gal/(sq ft)(day)				EC, μmhos/cm				COD mg/l	NH_3-N mg/l
										1	2	3	4	1	2	3	4	1 - 4	1 - 4
22 Sep 70	65	1.29	4.7	HCl	35	5000	214	-	0.3	10.9	5.9			380	410			10.1	-
23 Sep 70	65	1.29	4.8	HCl	34	6000	-	9.0	0.6	9.8	5.5			450	470			-	0.8
24 Sep 70	65	2.58	4.9	HCl	34	6400	196	-	0.4	8.6	4.8			480	465			9.1	-
25 Sep 70	65	2.58	5.8	HCl	36	3600	-	-	5.8	9.4	6.3			280	220			-	-
26 Sep 70	65	2.58	4.7	HCl	36	3600	101	-	-	7.0	4.8			430	600			6.8	-
27 Sep 70	65	2.58	4.6	HCl	36	3900	-	-	5.5	6.9	5.0			460	660			-	-
28 Sep 70	65	2.58	4.9	HCl	36	4400	-	-	23.0	6.3	5.8			560	1400			-	-

Appendix E
PERFORMANCE AND WATER QUALITY CHARACTERISTICS SECONDARY EFFLUENT, NONRECIRCULATING SYSTEM
(700 psig, 2% Recovery, 2.58 ft/sec Axial Velocity, H_2SO_4 Addition)

Date	FEED WATER						PRODUCT WATER									
	Temp. °C	pH	EC	COD mg/l	NH_3-N mg/l	Turbidity Jtu	Flux, gal/(sq ft)(day)				EC, μmhos/cm				COD mg/l	NH_3-N mg/l
							1	2	3	4	1	2	3	4	1 - 4	1 - 4
22 Jul 70	31	5.4	2150	-	-	-	32.3[a]	32.3[b]	32.3[c]	32.3[d]	150[a]	52[b]	22[c]	56[d]	-	-
23 Jul 70	31	5.0	1650	-	-	7.4	23.1	16.6	17.8	22.5	39	35	28	57	-	-
24 Jul 70	32	5.7	1760	-	-	12	28.4[e]	35.0[f]	33.0[g]	24.7	60[e]	52[f]	47[g]	56	-	-
25 Jul 70	30	5.6	1750	-	-	6	21.9	23.7	23.7	21.9	45	44	38	46	-	-
26 Jul 70	28	5.5	1540	-	-	5.7	18.4	18.8	18.8	18.4	48	50	44	50	-	-
27 Jul 70	30	5.3	1800	-	-	4.3	18.7	16.8	16.8	15.6	61	58	52	60	-	-
28 Jul 70	30	5.5	1900	-	-	6.2	15.6	14.9	14.9	13.8	52	53	47	55	-	-
29 Jul 70	31	5.6	1845	-	-	6.6	15.0	15.0	15.0	14.4	52	53	47	56	-	-
30 Jul 70	32	5.7	1675	-	-	5.5	13.8	13.8	14.1	13.4	55	54	47	57	-	-
31 Jul 70	32	5.8	1925	-	-	5.3	15.6	13.8	14.1	13.0	47	49	46	53	-	-
1 Aug 70	33	5.5	1950	-	-	4.5	18.1	13.8	14.1	13.1	50	52	47	54	-	-
2 Aug 70	31	6.0	1925	-	-	4.3	16.3	12.5	13.1	12.5	57	56	48	56	-	-
3 Aug 70	31	5.4	1850	-	-	6.4	13.8	11.7	11.5	11.0	56	53	46	54	-	-
4 Aug 70	28	5.5	1550	-	-	3.6	16.0	12.0	12.2	15.9	49	46	50	47	-	-
5 Aug 70	29	5.9	1575	-	-	3.0	15.1	11.8	11.8	15.0	48	50	47	44	-	-
6 Aug 70	30	5.4	1750	-	-	2.6	18.1	18.1	20.1	19.8	55	47	41	49	-	-
7 Aug 70	34	5.9	2000	-	-	3.5	22.4	21.4	23.8	24.4	65	53	50	53	-	-
8 Aug 70	34	5.6	2025	-	-	3.0	18.6	17.5	20.2	20.4	53	52	48	53	-	-
9 Aug 70	31	5.4	1650	-	-	2.6	16.5	16.0	17.5	17.7	100	55	48	49	-	-

[a]Tube 78-II; [b]Tube 87-I; [c]Tube 93-I; [d]Tube 85-I; [e]Tube 82-I; [f]Tube 76-II; [g]Tube 77-II

Appendix E (continued)

PERFORMANCE AND WATER QUALITY CHARACTERISTICS
SECONDARY EFFLUENT, NONRECIRCULATING SYSTEM
(700 psig, 2% Recovery, 2.58 ft/sec Axial Velocity, H_2SO_4 Addition)

Date	FEED WATER						PRODUCT WATER									
	Temp. °C	pH	EC	COD mg/l	NH_3-N mg/l	Turbidity Jtu	Flux, gal/(sq ft)(day)				EC, μmhos/cm				COD mg/l	NH_3-N mg/l
							1	2	3	4	1	2	3	4	1 - 4	1 - 4
10 Aug 70	30	5.4	1750	-	-	3.5	16.3	16.1	17.9	18.1	50	48	52	51	-	-
11 Aug 70	31	5.4	1800	-	-	1.7	16.2	15.7	17.3	17.8	53	49	44	50	-	-
12 Aug 70	31	5.4	2000	-	-	1.5	15.8	15.5	17.1	17.6	60	53	51	54	-	-
13 Aug 70	33	5.6	1850	156	-	2.6	15.6	15.1	16.4	17.1	60	52	49	62	-	-
14 Aug 70	34	5.4	2250	-	-	-	15.6	15.0	17.4	17.4	72	58	58	60	-	-
15 Aug 70	32	5.4	2100	-	-	2.4	15.9	15.1	18.4	18.4	73	62	126	52	-	-
16 Aug 70	32	5.2	2800	-	-	1.5	15.3	14.8	17.4	17.6	61	59	82	75	-	-
17 Aug 70	32	5.4	2075	-	-	4.0	15.2	14.7	17.1	17.1	80	63	110	71	-	-
18 Aug 70	32	5.3	1900	55	-	4.0	14.4	13.7	15.7	16.0	63	128	92	64	3.9	-
19 Aug 70	32	5.0	1910	-	-	3.9	14.1	13.6	15.3	15.8	76	56	58	52	-	-
20 Aug 70	32	5.0	1800	-	-	4.3	14.0	13.4	13.5	15.6	57	54	54	52	-	-
21 Aug 70	30	5.5	1850	-	-	5.5	14.4	13.6	15.7	16.2	56	49	60	51	-	-
22 Aug 70	29	5.7	1850	22	-	4.4	13.6	13.0	15.3	15.9	52	48	82	50	0.8	-
23 Aug 70	32	5.7	1670	-	-	3.2	13.8	13.1	32.9[h]	16.1	74	142	-[h]	49	-	-
24 Aug 70	32	5.3	2100	-	-	3.3	13.5	13.2	28.8	15.2	54	51	53	48	-	-
25 Aug 70	34	5.3	2050	92	4.2	5.0	13.3	13.1	22.2	14.6	56	58	54	51	15.6	0.5
26 Aug 70	32	5.3	2000	60	-	5.3	13.0	12.5	21.7	14.5	49	55	53	56	4.4	-
27 Aug 70	33	5.0	2050	90	2.0	20	12.4	12.2	19.3	13.9	50	51	50	54	4.3	0.35
28 Aug 70	32	5.3	2050	-	-	13	12.7	12.5	20.4	14.6	49	53	47	54	-	-

[h] Tube 188-I

Appendix E (continued)
PERFORMANCE AND WATER QUALITY CHARACTERISTICS
SECONDARY EFFLUENT, NONRECIRCULATING SYSTEM
(700 psig, 2% Recovery, 2.58 ft/sec Axial Velocity, H_2SO_4 Addition)

Date	FEED WATER						PRODUCT WATER									
	Temp. °C	pH	EC	COD mg/l	NH_3-N mg/l	Turbidity Jtu	Flux, gal/(sq ft)(day)				EC, μmhos/cm				COD mg/l	NH_3-N mg/l
							1	2	3	4	1	2	3	4	1 - 4	1 - 4
29 Aug 70	31	5.5	2000	81	-	15	12.3	11.9	19.8	15.1	50	54	48	54	13.3	-
30 Aug 70	32	5.5	2000	-	-	13	12.3	11.7	18.7	14.8	48	53	48	52	-	-
31 Aug 70	33	5.3	2050	-	-	-	11.7	12.0	14.4	13.6	77	60	52	53	-	-
1 Sep 70	33	5.4	1925	-	-	4.6	11.3	11.1	14.8	13.4	121	62	49	52	-	-
2 Sep 70	-	-	-	-	-	- -	11.4	10.7	14.2	13.1	68	51	46	48	-	-
3 Sep 70	32	5.2	1750	-	1.3	2.2	12.5	11.7	19.5	14.8	102	52	47	57	-	0.03
4 Sep 70	31	5.5	1940	-	-	1.5	12.3	12.1	18.9	14.6	100	48	40	49	-	-
5 Sep 70	31	5.1	1850	25	-	1.9	11.7	12.1	18.3	14.1	86	54	45	51	1.8	-
6 Sep 70	32	5.3	1800	-	-	1.7	14.7	11.6	17.5	13.9	101	57	48	53	-	-
7 Sep 70	32	5.5	1710	-	-	2.2	11.9	11.3	17.2	13.6	104	59	50	52	-	-
8 Sep 70	32	5.5	1850	78	-	1.3	12.2	11.5	17.5	13.8	188	79	52	53	-	-
9 Sep 70	32	5.5	1925	-	0.9	1.1	11.4	11.1	16.5	13.1	140	55	50	56	-	0
10 Sep 70	33	5.1	1700	25	-	1.0	12.1	11.4	16.9	17.1	168	63	47	52	6.2	-
11 Sep 70	33	5.2	1950	-	-	1.0	14.6	11.6	16.9	13.5	480	55	46	52	-	-
12 Sep 70	31	5.0	1850	45	-	1.5	28.3	10.9	15.9	13.2	1200	60	47	52	0	-
13 Sep 70	30	5.4	1825	-	-	1.3	-	10.6	-	13.7	-	63	-	54	-	-
14 Sep 70	31	5.5	1900	-	-	1.4	56.5[i]	10.9	18.1	13.0	84[i]	58	-	64	-	-
15 Sep 70	30	5.6	1850	56	-	2.8	33.2	10.6	16.2	12.6	76	78	61	74	0.9	-
16 Sep 70	32	5.3	1775	-	2.0	9.0	25.2	10.7	16.7	12.5	130	61	50	51	-	0.1

[i] Tube 279-1

Appendix E (continued)

PERFORMANCE AND WATER QUALITY CHARACTERISTICS
SECONDARY EFFLUENT, NONRECIRCULATING SYSTEM
(700 psig, 2% Recovery, 2.58 ft/sec Axial Velocity, H_2SO_4 Addition)

Date	FEED WATER						PRODUCT WATER									
	Temp. °C	pH	EC	COD mg/l	NH_3-N mg/l	Turbidity Jtu	Flux, gal/(sq ft)(day)				EC, μmhos/cm				COD mg/l	NH_3-N mg/l
							1	2	3	4	1	2	3	4	1 - 4	1 - 4
17 Sep 70	32	5.0	1875	82	-	8.4	21.5	10.0	16.0	17.3	91	100	67	70	-	-
18 Sep 70	31	5.6	1875	-	-	3.5	20.8	9.6	15.8	11.9	91	73	54	57	-	-
19 Sep 70	31	5.7	1900	91	-	11	18.9	8.9	14.8	11.2	74	83	57	58	5.6	-
20 Sep 70	31	5.3	1820	-	-	18	17.1	8.0	13.9	10.0	119	65	47	52	-	-
21 Sep 70	31	5.3	1975	-	-	18	15.5	7.2	12.8	9.4	112	82	53	58	-	-
22 Sep 70	32	6.0	1950	144	-	8.5	15.2	7.3	12.5	9.4	84	82	63	67	0	-
23 Sep 70	33	5.1	2125	-	5.3	12	14.7	7.0	12.2	8.9	150	88	60	76	-	0.3
24 Sep 70	32	5.5	1950	94	-	12	13.8	6.7	11.5	8.3	140	73	56	62	0.8	-
25 Sep 70	32	5.5	1825	-	-	6.5	35.1	21.2	24.3	15.3	74	57	52	57	-	-
26 Sep 70	34	5.2	1700	68	-	6.2	24.4	19.4	21.2	14.7	77	58	48	54	0	-
27 Sep 70	34	5.0	2200	-	-	5.3	25.5	18.8	22.0	14.5	69	57	44	49	-	-
28 Sep 70	33	5.2	2300	-	-	5.3	22.5	17.7	20.4	14.0	56	44	41	48	-	-
29 Sep 70	32	5.2	1875	91	-	4.1	21.4	17.5	19.5	13.7	58	41	40	45	3.0	-
30 Sep 70	33	5.0	2025	-	-	4.3	20.0	16.9	19.6	13.5	63	52	48	60	-	-
1 Oct 70	31	5.0	1925	57	-	3.1	18.5	15.8	17.7	12.7	65	41	35	44	2.2	-
2 Oct 70	32	5.3	2000	-	-	4.9	19.2	16.7	18.7	15.5	70	52	42	43	-	-
3 Oct 70	30	5.5	2050	57	-	5.8	17.8	15.8	17.8	12.7	70	73	47	44	10.5	-
4 Oct 70	32	4.9	2050	-	-	4.1	17.5	15.6	14.4	12.3	83	47	38	45	-	-
5 Oct 70	30	5.0	1975	-	-	3.3	16.1	15.0	15.4	12.1	78	44	50	42	-	-

Appendix E (continued)
PERFORMANCE AND WATER QUALITY CHARACTERISTICS
SECONDARY EFFLUENT, NONRECIRCULATING SYSTEM
(700 psig, 2% Recovery, 2.58 ft/sec Axial Velocity, H_2SO_4 Addition)

Date	FEED WATER						PRODUCT WATER									
	Temp. °C	pH	EC	COD mg/l	NH_3-N mg/l	Turbidity Jtu	Flux, gal/(sq ft)(day)				EC, μmhos/cm				COD mg/l	NH_3-N mg/l
							1	2	3	4	1	2	3	4	1 - 4	1 - 4
6 Oct 70	29	5.3	1750	78	-	5.5	16.0	14.4	16.1	11.5	51	40	32	40	2.3	-
7 Oct 70	30	5.4	2000	-	-	5.6	15.9	14.5	16.3	11.6	52	40	37	39	-	-
8 Oct 70	30	5.8	1900	80	-	2.3	15.9	14.4	16.0	11.2	59	42	36	40	0	-
9 Oct 70	30	5.4	1875	-	-	2.6	15.6	14.0	15.8	11.2	60	40	36	42	-	-
10 Oct 70	29	5.9	1850	36	-	3.4	15.0	13.5	15.4	11.0	58	38	33	40	0	-
11 Oct 70	29	5.5	1760	-	-	2.7	15.3	13.8	15.6	11.1	64	40	36	40	-	-
12 Oct 70	29	5	1750	-	-	2.8	16.1	14.1	15.8	11.1	62	40	35	40	-	-
13 Oct 70	30	5.5	1875	34	-	5.0	13.6	12.5	14.2	10.2	74	41	39	41	5.2	-
14 Oct 70	29	5.3	1700	-	-	21	13.1	12.0	13.7	9.9	56	36	30	35	-	-
15 Oct 70	29	5.6	1800	-	-	11	13.3	11.9	10.3	9.5	56	37	78	41	-	-
16 Oct 70	-	5.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17 Oct 70	20	5.7	1950	-	-	24	12.3	11.0	8.8	8.8	63	39	85	43	-	-
18 Oct 70	29	5.5	2000	82	-	4.7	12.5	11.4	8.3	9.2	66	43	88	48	0	-
19 Oct 70	29	5.6	1950	-	-	5.0	12.0	10.8	8.0	8.9	78	47	94	49	-	-
20 Oct 70	29	5.1	1875	72	-	3.8	12.0	11.9	8.0	8.9	72	52	96	47	1.4	-
21 Oct 70	29	5.4	1775	-	-	1.6	41.6	10.5	7.7	8.6	61	43	92	44	-	-
22 Oct 70.	28	6.0	1760	49	-	1.7	11.7	10.6	7.7	8.6	71	44	92	46	3.8	-
23 Oct 70	27	5.6	1750	-	-	5.3	12.0	10.9	7.8	9.1	66	37	80	46	-	-

Appendix E (continued)
PERFORMANCE AND WATER QUALITY CHARACTERISTICS
SECONDARY EFFLUENT, NONRECIRCULATING SYSTEM
(700 psig, 2% Recovery, 2.58 ft/sec Axial Velocity, H_2SO_4 Addition)

Date	FEED WATER						PRODUCT WATER									
	Temp. °C	pH	EC	COD mg/l	NH_3-N mg/l	Turbidity Jtu	Flux, gal/(sq ft)(day)				EC, μmhos/cm				COD mg/l	NH_3-N mg/l
							1	2	3	4	1	2	3	4	1 - 4	1 - 4
24 Oct 70	28	5.9	1800	-	-	9.0	11.9	11.1	7.8	8.1	77	49	84	46	-	-
25 Oct 70	29	5.4	1850	54	-	-	11.4	10.3	7.0	8.4	45	54	98	50	7.9	-
26 Oct 70	29	5.3	1850	-	-	1.5	11.3	10.3	7.0	8.6	70	46	84	49	-	-
27 Oct 70	29	4.9	1800	66	-	4.5	10.9	10.8	6.9	8.3	41	49	85	46	1.4	-
28 Oct 70	32	5.5	1850	-	3.3	6.3	10.9	10.0	6.7	8.3	74	47	83	46	-	-
29 Oct 70	29	-	1700	-	-	-	11.7	10.6	7.7	8.7	77	47	84	49	-	-

Appendix F

PERFORMANCE AND WATER QUALITY CHARACTERISTICS
SECONDARY EFFLUENT, RECIRCULATING SYSTEM
(700 psig, 2% Recovery, 2.58 ft/sec Axial Velocity, HCl Addition)

Date	FEED WATER							PRODUCT WATER									
								Flux, gal/(sq ft)(day)				EC, μmhos/cm				COD	NH_3-N
	Recovery %	Temp °C	pH	EC	COD mg/l	NH_3-N mg/l	Turbidity Jtu	1	2	3	4	1	2	3	4	mg/l 1 - 4	mg/l 1 - 4
29 Sep 70*	80	-	-	-	-	-	-	48.3[a]	74.0[b]			-	-			-	-
30 Sep 70	80	36	6.2	4000	-	-	7.6	24.7	27.2			225	220			-	-
1 Oct 70	80	32	5.6	4400	175	-	4.3	10.3	10.3			560	535			5.2	-
2 Oct 70	80	36	5.7	3500	-	-	12.5	4.7	4.4			520	540			-	-
3 Oct 70*	80	34	5.5	2200	-	-	6.3	4.4	4.4			420	500			-	-
4 Oct 70	80	34	5.3	2800	-	-	4.1	4.1	4.1			540	580			-	-
5 Oct 70	80	32	4.9	3900	-	-	5.6	3.7	3.7			740	670			-	-
6 Oct 70*	80	30	4.8	4800	119	-	18	21.2	20.8			315	280			3.7	-
7 Oct 70*	80	31	-	5400	-	-	13	15.2	15.9			735	810			-	-
8 Oct 70	80	32	5.6	3700	-	-	5	8.4	8.6			980	1040			-	-
18 Oct 70*	70	32	6.3	4400	144	-	19	15.5	15.5			370	415			8.6	-
19 Oct 70	70	33	4.3	4200	-	-	8.4	7.0	7.0			540	550			-	-
20 Oct 70	70	33	5.7	3800	251	-	5.2	5.9	5.8			690	720			5.0	-
21 Oct 70*	50	32	5.8	3900	-	-	11.0	21.6	21.9			310	260			-	-
22 Oct 70	50	32	6.4	3300	208	-	35	6.7	6.5			400	430			5.3	-
23 Oct 70	50	30	5.3	2550	-	-	-	6.4	5.8			600	660			-	-
24 Oct 70	50	33	5.3	2500	-	-	5.0	4.9	4.7			300	310			-	-
25 Oct 70	50	32	4.5	3600	212	-	4.0	3.9	3.8			580	590			13.0	-
26 Oct 70	50	32	5.0	3800	-	-	3.7	3.9	3.7			660	615			-	-
27 Oct 70	50	32	5.1	3500	214	-	8.0	12.4[c]	3.0			720[c]	-			4.8	-
28 Oct 70	50	29	5.4	3900	-	10.5	7.6	8.4	3.4			760	840			-	0.5

[a] Tube 289-I; [b] Tube 292-I; [c] Tube 286-I.

*Enzymatic Cleansing.

1 Accession Number	2 Subject Field & Group	SELECTED WATER RESOURCES ABSTRACTS INPUT TRANSACTION FORM
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5 Organization

Envirogenics Co., Division of Aerojet-General Corp., El Monte, California

6 Title

REVERSE OSMOSIS RENOVATION OF PRIMARY SEWAGE

10 Author(s)

Feuerstein, D. L.

16 Project Designation

17040 EFQ

21 Note

22 Citation

23 Descriptors (Starred First)

*Demineralization, *Reverse osmosis, *Sewage treatment, *Water reuse, Membrane processes

25 Identifiers (Starred First)

Organics removal, Solids removal

27 Abstract

The feasibility of renovating primary sewage effluent by the reverse osmosis process was investigated under a variety of conditions. Secondary effluent was also processed for comparison. High feed water velocities were found to be necessary to maintain acceptable product water flux levels; at 12.9 ft/sec, performance with primary effluent was comparable to secondary effluent at 2.6 ft/sec. Below 6.4 ft/sec, gross membrane fouling occurred with primary effluent. Sizable flux restorations were achieved by occasional membrane cleansing with an enzyme-active laundry formulation and short-term depressurization of the system also restored flux, but to a lesser degree. Rejections of major pollutants were high. Values at 2.6 ft/sec averaged 94% for TDS, 94% for COD, 85% for ammonium nitrogen and 100% for turbidity, while values at 12.9 ft/sec were 98% for TDS, 98% for COD, and 100% for turbidity. Calcium sulfate deposition was experienced during the program because of high indigenous concentrations of the ions in the sewage used in the tests. (Wilson-Envirogenics).

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